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ABSTRACT

The twenty experiments in this text have been designed to give the scientific glassblowing technician the opportunity to use scientific glass apparatus in the study of physical science. Primary emphasis of these experiments is on the practical application of the physical science program as a working tool for the scientific glassblowing technician. The experiments are: precision measurement, elasticity and tensile strength, Archimedes principle, specific gravity and density of solids and liquids, Boyle's Law of Gases, study of the thermocouple, linear expansion with temperature, heating value of fuel, specific heat of solids, latent heat and change of state, velocity of sound by resonance methods, photometry and illumination. Also: study of spherical mirrors, index of refraction, image formation by a thin lens, polarization of light, internal strain in glass, glass tube bending and breaking points, glass annealing, and glass strength testing. The purpose of each experiment is stated, apparatus listed, and an information section provided. The procedure is described, followed by questions for analysis and interpretation. (Author/DS)

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STATE OF NEW JERSEY
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PHYSICAL SCIENCE EXPERIMENTS FOR SCIENTIFIC GLASSBLOWING TECHNICIANS

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EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

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PREFACE

This laboratory text is designed to give the scientific glassblowing technician the opportunity to use scientific glass apparatus in the study of physical science.

The experiments chosen for this project were selected with primary emphasis on the practical application of the physical science program as a working tool for the scientific glassblowing technician.

These experiments will require maximum cooperation between the scientific glassblowing instructor and the physical science instructor. Since the burners used in most physical science laboratories do not produce enough or the kind of heat necessary for working with glass, several of the experiments will have to be performed in the glassblowing laboratory.

If it is possible, the apparatus in each of these experiments should be fabricated in the school's laboratory for use in the physical science experiments.

Some of the equipment needed will be too complex for the first year student to fabricate while taking the physical science course: these items can be fabricated by the second year student for use in the physical science laboratory.

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INTRODUCTION

The experiments to be accomplished in this series will be keyed as closely as possible to the study of glass and the application of blown scientific glass apparatus developed in the school's glassblowing laboratory.

This course will be offered as the first science course for the glassblower; therefore, he will not have as yet developed the ability to design and fabricate his own apparatus. The experience in these laboratory experiments will be of assistance in helping him understand the accuracy and skill necessary for the good design and fabrication of scientific laboratory glassware.

The apparatus used in these experiments should be encouraged as special projects in the Glass Fabrication and Design Course in the second year of Scientific Glassblowing Technology. This fabrication of the apparatus will afford the student an opportunity to build apparatus that he understands how to use. It will act as an incentive to the students who follow in the program and give some insight into the standards of accuracy needed in glass fabrication.

Laboratory reports will be written for each experiment using the format on the following pages.

LABORATORY REPORT FORMAT

Name and Number of Course

Experiment No. _____ Name _____

Date _____

Lab Section _____

Title _____ Instructor _____

Body of Report

Purpose:

State the general principle being studied and any specific results to be obtained. The brief statement of purpose should be the product of your own thought.

Method:

Describe briefly how the experiment was performed. The description should be in your own words. **It should not be copied from the manual.** Use a neat, lettered sketch or diagram whenever possible. Sketches may be in pencil.

Data Sheet:

This is the actual data sheet on which you recorded data in the laboratory. Form the habit of neatness with your original laboratory notes so that they will be suitable for inclusion in the report.

Results:

What did you find from the investigation? Show the calculations you used. These should be in skeleton form. Do not clutter up the laboratory report with arithmetic.

Summarize the results in a table whenever possible. Display your answers prominently and in such a manner that the person who reads the report will be able to tell readily that you have actually verified the principle or law being studied. Give careful attention to proper units.

Analysis and Interpretation:

Identify and discuss your errors and the possible sources of error in the particular experiment. Calculate the percent error of your results. Point out practical applications of the principle being studied. Did the experiment illustrate or verify the principle under discussion? Prove to yourself and to the instructor that it did or did not.

EXPERIMENT I

Precision Measurement

Purpose:

To study some instruments and methods of precision measurement; and to compute the volume and density of glass apparatus.

Apparatus:

Steel rule; inside and outside calipers both vernier and micrometer (English and metric); comparator with dial accurate to 0.0001 inch; laboratory balance and weights; set of gage blocks (English and metric); laboratory glass beakers; flasks; cylinders; rods; and tubes (calibrated and uncalibrated).

Information:

Measurements are one of the most essential parts of the scientific glassblower's fabrication project. Accuracy of .001 inch to .00001 inch are common in scientific apparatus. The student must be thoroughly familiar with both the English and metric system of measurement. Most scientific glass apparatus is built to metric specifications. The student will review units of measurement in both the English and the metric systems and the conversion factors from one system to the other.

Procedure:

With the instruments, and the aid of manufacturers' specification charts, practice until accurate readings from vernier caliper and micrometer caliper can be obtained easily and quickly.

Part I. Conventional Measuring Instruments

1. With the steel rule, take and record all measurements necessary for calculating the volume of a glass rod, tube, beaker, and cylinder.

$$V = \pi r^2 h \quad \text{or} \quad V = \frac{\pi d^2 h}{4}$$

2. Repeat measurements from step 1 with the English vernier caliper.
3. Repeat measurements from step 1 with the metric vernier caliper.
4. With both English and metric micrometer calipers measure the diameter of the rod, beaker, tube, and cylinder.
5. Check the accuracy of the measurement in step 4 by using the comparator with the dial indicator.
6. Weigh the beaker, rod, tube, and cylinder (calibrated and uncalibrated) on the laboratory balance to the nearest .01 gram.

Part II. Volumetric Calibration

The space or volume that a liquid occupies at a fixed temperature and pressure is a constant. With this fundamental concept in mind, if 250 milliliters (ml.) of water weighs 250 gms at a measured temperature when in a quart jar, it would weigh the same, if the temperature remains constant, when placed in a pint jar.

1. Place 10 ml. of water in the calibrated beaker and cylinder. Weigh on the laboratory balance to the nearest .01 gram.
2. Repeat Step 1 using 25 ml. of water.
3. Repeat Step 1 using 50 ml. of water.
4. Repeat Step 1 using 100 ml. of water.
5. Repeat Step 1 using 200 ml. of water.

Calculations:

Part I.

Compute the volume of each test object in both cubic feet and cubic centimeters accurate to three significant figures. Compute the density of each test object. Density equals weight per unit volume.

Part II.

Determine the weight of 10 ml., 25 ml., 100 ml., and 200 ml. of water at the measured temperature by subtracting the weight of the calibrated beaker and cylinder (from Part I step 6) from each of the readings taken in Part II steps 1 through 5. These weights are your reference volumes at the measured temperature.

Analysis and Interpretation:

Review the instructions and format for writing the laboratory report. Include a discussion in paragraph form of the following points in the final section of your laboratory report.

1. With sketches, explain the operation and reading of the vernier and micrometer calipers.
2. Determine how measuring devices are used, from library references, industry field trips, and questioning your glass technology instructor.
3. What does density mean? Why is it important in the design of apparatus?

EXPERIMENT II

Elasticity and Tensile Strength

Purpose:

To study the elasticity, tensile, compression and shearing strength of a rod, and to determine Young's modulus and ultimate tensile strength of a rod.

Apparatus:

Scott Engineering Properties of Materials Education System Model 9014; Scott Polariscope Model 9015; hard- and soft-glass test specimens; brass and steel test specimens; micrometer calipers; and vernier calipers.

Information:

Every material is elastic to some degree. A material is said to be elastic if, after a deformation of any kind, it returns to its original shape and size.

Rubber bands, tennis balls and golf balls are by popular notion believed to be good examples of elasticity; but, in actual fact, such things as steel, ivory and glass are much more elastic. There is a limit to the force which may be applied to a body and still have it return to its original undistorted state. This limiting force is called the elastic limit. If this limiting force is exceeded, the material will be permanently distorted. If the force is still greater, the material will eventually pull apart and break. Some materials which are transparent or translucent to light cause interference or bending of light when they are placed under stress. These materials, such as many plastics, lucite, plexiglass and glass, allow the apparent observation of change in molecular structure under tensile, compressive, and shearing stress.

Tensile, compressive and shearing **stress** may be determined for a material by the formula shown below.

$$\text{stress} = \frac{F}{A} = \frac{\text{force applied}}{\text{area of cross section}}$$

Whenever a force is applied, the test material will change in shape. The relationship of the original shape to the change in shape is called **strain**. For tensile or compressive forces,

$$\text{strain} = \frac{\text{change in length}}{\text{original length}} = \frac{e}{L}$$

Hook's law states that strain is proportional to stress for elastic materials within their elastic limit. The proportionality ratio is called the modulus of elasticity.

$$Y = \frac{\text{stress } F/A}{\text{strain } e/L} = \frac{FL}{Ae}$$

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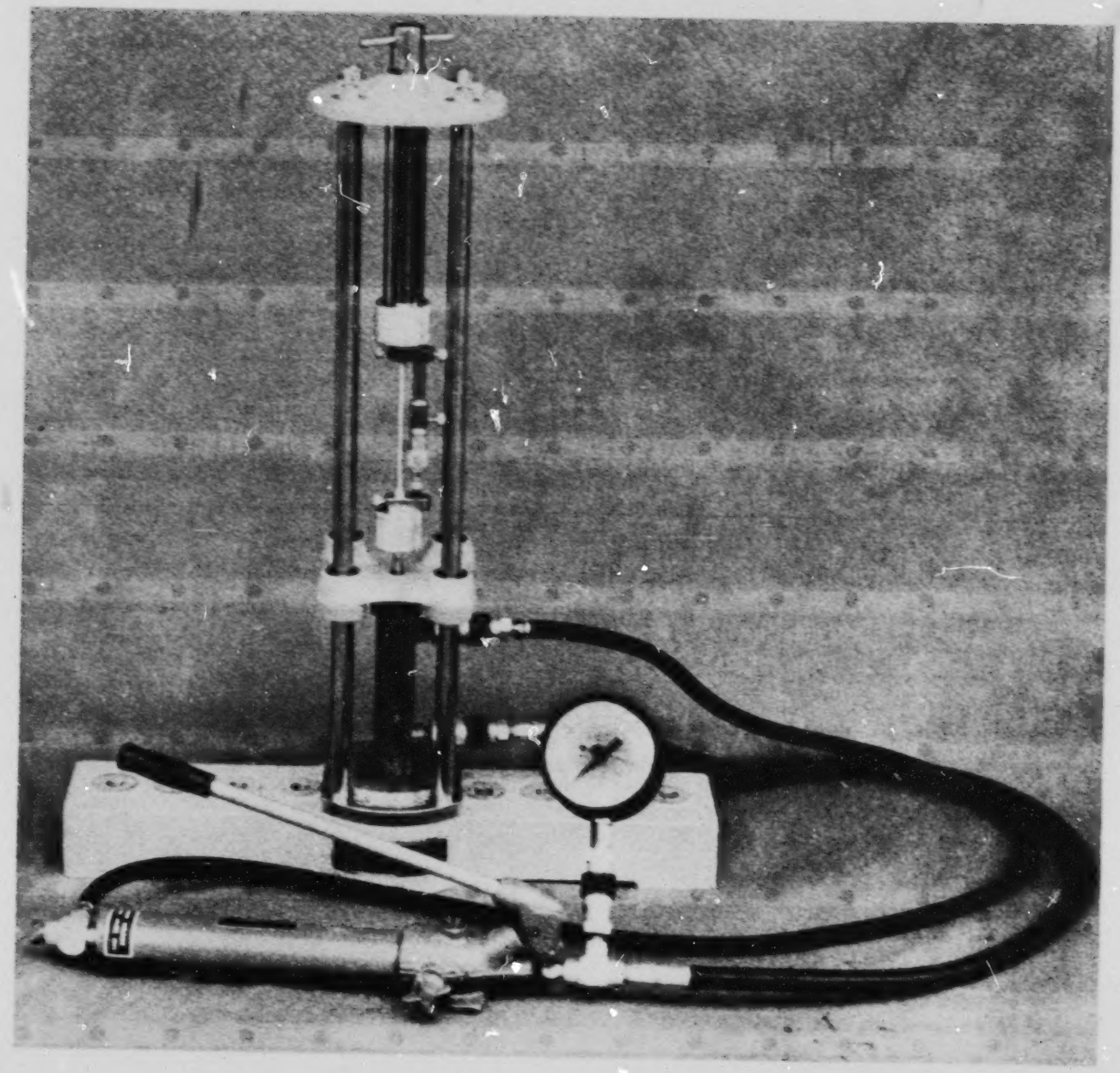


Ultimate tensile strength. The force per unit area (stress) at the instant a material pulls apart is known as the ultimate strength. All of the gage readings in this data table will be in pounds per square inch (psi); therefore, the student will have to convert from pressure in psi to force in pounds to set up the measurement increments called for in this experiment. The force-pressure relationship will be used.

$$P = \frac{F}{A_R} \qquad or \qquad F = PA_R$$

where:

P = gage pressure in psi

F = pounds

A_R = hydraulic jack ram area

.373 in^2 = jack ram area when it is extending or being used to give a compressive force.

.223 in^2 = jack ram area when it is retracting or being used to give a tensional force.

Procedure:

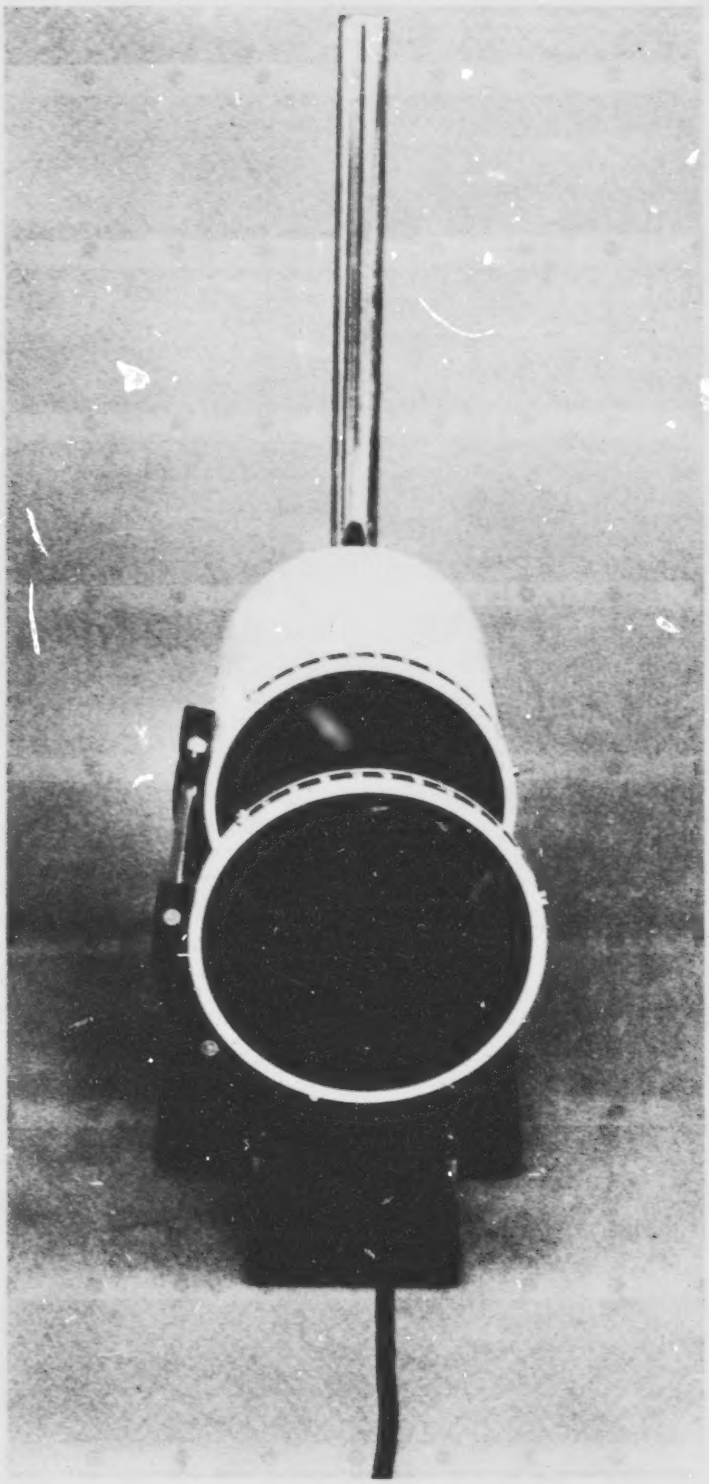
Part I. Tensile Stress (Elasticity and Tensile Strength)

1. Set up the model 9014 using the long rods to give the long configuration.
2. Measure length of sample between fillet ends (between rod ends for glass) and sample diameter (sample series .00001).
3. Install micrometer on a sample with adapters 14–16–000 and 14–17–000 and extension 14–05–000 and screw sample into lower holder 14–00–021.
4. Make sure pump hoses are set to tension with heavier hose on top port of jack and the polariscope in place for the glass and plastic samples.
5. Load samples in increments and record elongation.

Sample	Increment	Maximum
Aluminum	50 lb.	350 lb.
Steel	100 lb.	600 lb.
Brass	100 lb.	600 lb.
Plastic	10 lb.	100 lb.

When pressure has been released after completion of experiment, record length and diameter of sample again to determine permanent sample deformation.

6. Sketch the change in light patterns within the test specimen. Note color and location of bands.
7. Repeat Steps 3 through 6 for hard glass.
8. Repeat Steps 3 through 6 for plastic.
9. Repeat Steps 3 through 5 for brass.
10. Repeat Steps 3 through 5 for steel.



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Part II. Compression Test (glass and plastic only; elasticity and tensile strength)

1. Set up the model 9014 using the short rods to give the short configuration. The setup for axial compression is shown in Fig. 18, p. 30 of Scott Manual 9014. The spider must be raised to put in the micrometer adapter 14–06–000. Before putting in the top yoke make sure that space support 14–000–010 is in place between the rods. Use the long spacer 14–000–009.
2. Set up the Polariscope model 9015 with model 9014. Adjust the analyzer (front pin), and the quarter wave plate (pins on back of analyzer portion and front of main unit) to 0^0.
3. Measure length and diameter of sample to be tested (.0002 series).
4. Make sure the pump is set up for compression (heavy hose at the bottom port of jack) and 1000 psi gage is in position on the pump.
5. Turn on white light in polariscope and put plastic sample in place. Slowly pump up 400 psi gage pressure and observe color change and bands forming as pressure is applied. Each band indicates a region of constant force. Sketch the change in light patterns within the test specimen. Note color and location of bands.
6. Release pressure and reapply pressure, recording compression and force applied at convenient intervals to 600 psi of pressure.

Part III. Shearing Stress (in brass and steel only)

1. Set up Scott Materials Test as shown in figure 5 and 7 of the Scott Engineering Instruction Manual 9014.
2. Measure and record diameter of shear pin on apparatus.
3. Insert brass shear test specimen.
4. Begin to apply force to specimen. Record applied force.
5. Repeat Steps 2 through 4 for steel test specimen.

Calculations:

Part I. Compute the cross-sectional area of each object. Using recorded force data and area calculations, compute the tensile stress in each object. Using recorded measurements of change in length and original length, compute the strain on each object. Determine Young's modulus for each type of material.

Part II. Sketch and color the action of the glass and plastic reaction under tension and compression.

Part III. Calculate the area of the shear pin and using the force data determine the ultimate shearing stress in the brass and steel.

Analysis and Interpretation:

Plot a stress-to-strain curve for each material under tension.

Label the elastic limit on each plot.

1. How do the values of stress, strain, and Young's Modulus compare to reference values?
2. In brief, describe how this experiment would be used to aid in the design of glass apparatus.

EXPERIMENT III

Archimedes Principle

Purpose:

To study the principles of flotation and buoyancy and to verify Archimedes Principle.

Apparatus:

Overflow can and catch bucket; triple beam balance; soda lime glass block; lead glass block; cork block; water; glycerin; thermometer; and hydrometer.

Information:

Archimedes, an early Greek experimenter, states that an object in a fluid is buoyed up by a force equal to the weight of the fluid moved aside. If the body floats in the fluid, then the buoyant force must be equal to the weight of the object. Therefore, a floating object is said to displace its own weight in a fluid in which it floats. If the object is more dense or heavier than the fluid, it sinks and displaces an amount of fluid equal to its volume; the buoyant force is equal to the weight of the volume of fluid moved aside. The buoyant force equals the apparent loss in weight of the object when it sinks in the fluid.

$$F_B = W - W_1$$

where:

F_B = force of buoyancy
W = weight of an object in air
W_1 = apparent weight when submerged in a liquid

Since: $D = \frac{W}{V}$

then: $W_L = D_L V_L$

where:

W_L = weight of liquid displaced
D_L = density of the liquid
V_L = volume of the liquid

Then to prove Archimedes Principle, we must show that

$$F_B = W - W_1 = D_L V_L$$

or, buoyant force = weight of displaced liquid.

Procedure:

Part I. Using Water as the Liquid

1. Determine weight of soda lime glass block in air to the nearest .01 gm by suspending it from triple beam balance. Be sure to use a fairly large block so that a considerable volume of liquid will be displaced.
2. Fill the overflow can with water until it overflows into the catch bucket. When all dripping stops, empty and dry the catch bucket. Slowly lower the balance on the laboratory stand until the block has sunk below or floats free on the water surface. Catch all the water which overflows. Record this volume.
3. Determine the apparent weight of the block while it is hanging submerged in the water. Record this apparent weight as W_1. Measure the temperature of the water.
4. Repeat steps 1 through 3 above for lead glass block.
5. Repeat steps 1 through 3 above for cork block.

Part II. Using Glycerin

Repeat all the measurements in Part I for all objects.

Measure the density of the liquid with a hydrometer.

Calculations:

1. For both water and heavy liquid, show that Archimedes Principle for submerged bodies has been verified.
2. For both water and the heavy liquid, show that Archimedes Principle for floatation has been verified.

Analysis and Interpretation:

1. Analyze and discuss any errors found and the sources of these errors.
2. From your library references, summarize what has been learned of the history of the development of Archimedes Principle.
3. Practical application in the glassblowing field of the principle of flotation.

EXPERIMENT IV

Specific Gravity and Density of Solids and Liquids

Purpose:

To study the principles of specific gravity and density of solids and liquids.

Apparatus:

Triple beam balance; graduated cylinder; solid specimens (soda-lime glass, lead glass, borosilicate glass, aluminum, brass, steel, lead and cork); liquid specimens (glycerin, ethylene glycol); overflow can and catch bucket; sinker; hydrometers; and specific gravity bottles.

Information:

It will be recalled from Experiment 3 that the density is the weight per unit volume of a substance. Specific gravity is a concept of the relative heaviness of a substance compared to that of water.

$$\text{Specific gravity} = \frac{\text{density of a substance}}{\text{density of water}}$$

or $$sp\ gr = \frac{D_s}{D_w}$$

where $sp\ gr$ = specific gravity
D_s = density of a substance
D_w = density of water

But: $$D_s = \frac{W_s}{V_s} \quad and \quad D_w = \frac{W_w}{V_w}$$

where:

W_s = weight of a substance
V_s = volume of a substance
W_w = weight of water
V_w = volume of water

When substance and water have an equal volume, then

$$\text{Specify gravity} = \frac{D_s}{D_w} = \frac{\left(\frac{W_s}{V_s}\right)}{\left(\frac{W_w}{V_w}\right)} = \frac{W_s\ V_w}{W_w\ V_s} = \frac{W_s}{W_w} \quad (Since\ V_w = V_s)$$

The specific gravity of solids can be determined in several ways. The techniques differ in determining the equal volume of water.

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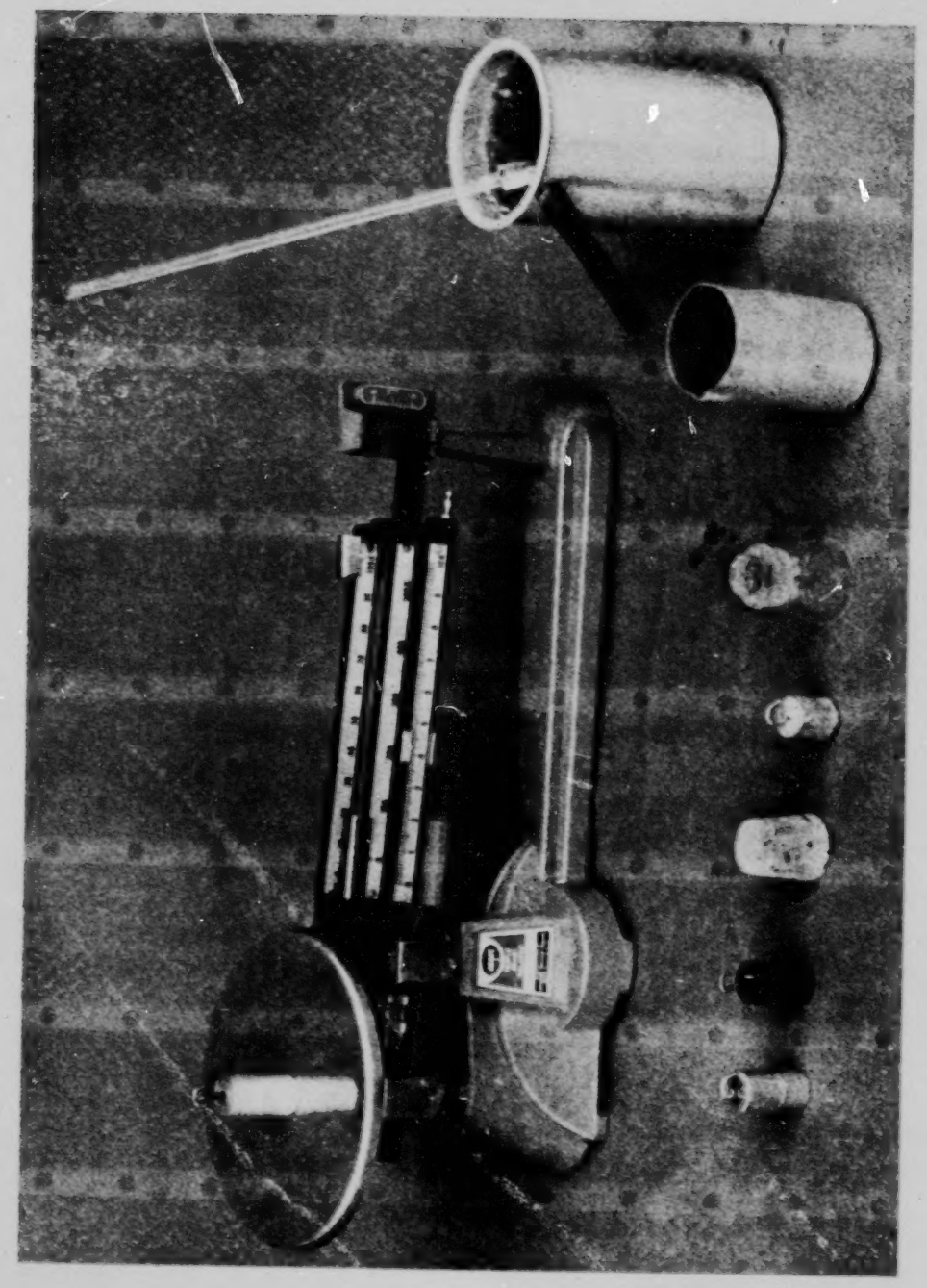

This experiment will use Archimedes Principle to make the determination of equal volume.

With solids lighter than water, a sinker may be used to pull the specimen under water so its displacement may be measured. The specific gravity of liquids may be determined by using specific gravity or pyconometer bottles. The bottle is filled with the sample liquid and the weight of this amount of liquid is determined. Then if the bottle is cleaned, dried and filled with water, the weight of an equal volume of water may be found since the same measuring bottle is used for both the liquid and water. Another method of determining the specific gravity of a liquid is to use Archimedes flotation principle. This method makes use of a calibrated hydrometer which will read the specific gravity directly.

Procedure:

Part I. Specific Gravity of a Solid

1. Solid heavier than water

   Weigh the solid in air to the nearest .01 gm. and record. Fill overflow can until water runs out of the spout into the catch bucket. Empty and dry the catch bucket. Immerse the solid in the overflow can; catch and weigh the overflow water. This is the volume of water equal to the volume of the solid. Take three trial readings for each heavy solid.

2. Solid Lighter than Water

   Weigh the solid to the nearest .01 gm. Fill the overflow can until water runs out the spout into the catch bucket. Attach a sinker to the light solid object. Immerse the sinker in overflow can until it is just covered by water. Empty and dry the catch bucket. Allow sinker to pull light solid object until it is completely immersed in the water. Catch and record the water overflow. This is the volume of water equal to the volume of the light solid object. Take three trials of this volume for each solid.

Part II. Specific Gravity of Liquids

1. Specfic gravity bottle to pyconometer method.

   Weigh the empty pyconometer with stopper to the nearest .01 gm and record. Fill the pyconometer with the test liquid and record this reading. Empty and dry the pyconometer. Fill the pyconometer with water, weigh and record. Repeat this for each of the test liquids.

Part III. Density of Solids and Liquids

Using data obtained from Parts I and II determine the density of each sample in $lbs./ft^3$ and gms/cm^3.

Calculations:

1. Determine the experimental values for the specific gravity of each of the solid specimens.
2. Determine the specific gravity of the liquids using data from the pyconometer method. Compare these values with the results of the hydrometer test.
3. Determine the density in lbs/ft^3 of each test specimen.
4. Compare values of specific gravity and density to standard reference values and calculate the percent error between the experimental results and reference data.

Analysis and Interpretation:

1. Analyze and discuss possible sources of error in this experiment.
2. Distingusih clearly between density and specific gravity. Why are they numerically the same in the metric system, but not in the English system?
3. How could Archimedes principle be used to determine the density of solids heavier than water?
4. Discuss several important industrial applications of the principle of density and specific gravity.
5. If the density of a material is known in the English system, what is the simplest way to find its specific gravity?

EXPERIMENT V

Boyle's Law of Gases

Purpose:

To study the relationship between pressure and volume of a gas when the temperature is constant.

Apparatus:

Closed-end J tube fabricated in the glass laboratory prior to laboratory experiment, and laboratory barometer.

Information:

The study of the gaseous state explains that gases have no definite volume. The volume of a given mass of gas (fixed number of molecules) varies greatly with changes in pressure or temperature. Pressure, volume, and temperature actually determine the condition of a gas at any given instant; therefore, these variables are referred to as the P–V–T conditions of a gas.

With a tube similiar to the tubes fabricated by students for this experiment, Robert Boyle, in 1622, found that, if the temperature of a gas remains constant while the absolute pressure is varied, the volume of the gas varies inversely with the absolute pressure which is applied.

In nature, pressure and temperature usually both vary simultaneously; but in the laboratory, it is possible by careful control to hold either pressure or temperature constant and observe the effect of the change in temperature or pressure on the volume of a gas. When the pressure is changed slowly, time is allowed for heat of compression to be lost to the surrounding environment, thus keeping the temperature constant.

Boyle found that when this occurred the relationship of pressure and volume could be expressed in the mathematical form shown below:

$$(1)\ P_1 V_1 = P_2 V_2$$

or

$$(2)\ P V = k$$

where:

P_1 = original absolute pressure

P_2 = new absolute pressure

V_1 = original volume

V_2 = new volume

k = the product of absolute pressure times volume, which is a constant

Equation (2) is the accepted mathematical form of Boyle's law. This equation will result in a hyperbola when it is used for a graphical plot. If absolute pressure is plotted

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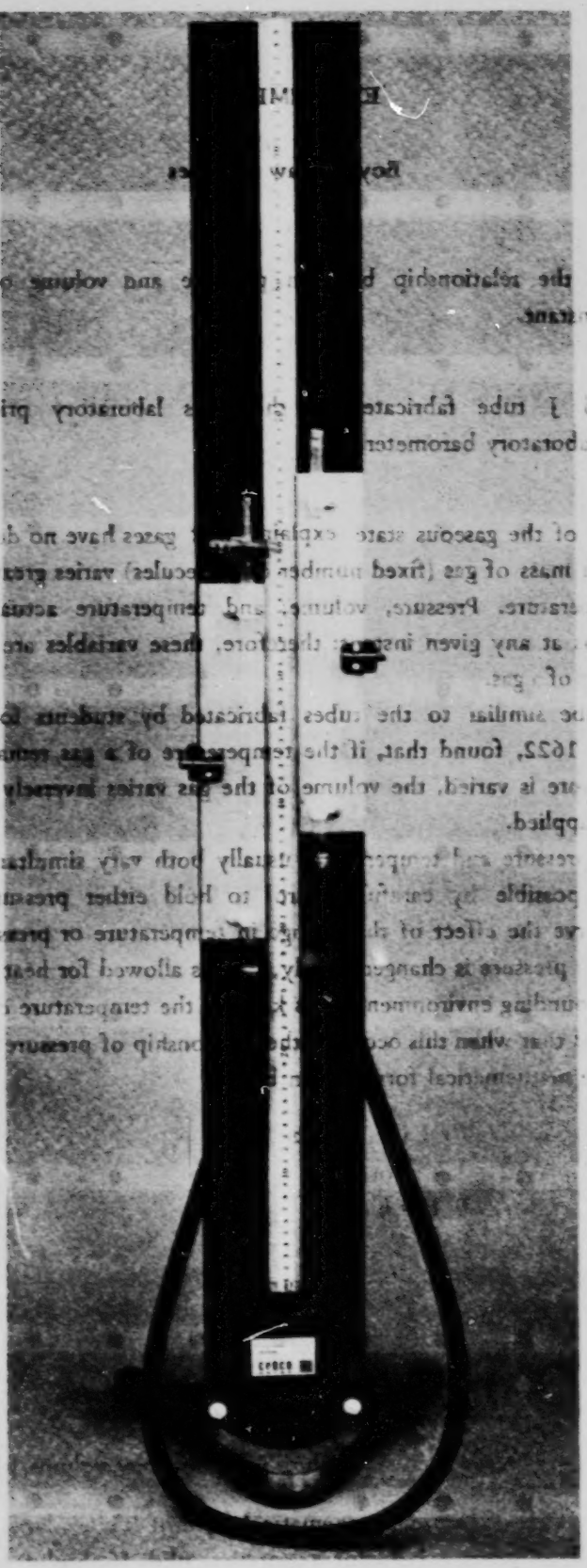

on the vertical axis and volume on the horizontal axis, a curve of the pressure-volume relationship according to Boyle's Law may be observed.

If you plot points P_1, V_1 and P_2, V_2 on a P–V plot, you will find that the rectangles formed by the axes and the distances of the points from the axes will be equal in area.

Procedure:

Begin the experiment by mounting the J tube on a board with a meter stick.

1. After mounting, record the position of the closed end of the J tube on the meter stick.
2. Pour small amounts of mercury (do not touch or spill) into open end of J tube. Record mercury levels in both open and closed tube as read from meter stick.
3. Add small amount of mercury to open end of J tube until about 15 readings of both open- and closed-tube levels have been recorded. (Be sure to wait at least a minute between each addition of mercury to give the temperature of the gas in the closed end of the tube time to stabilize to environmental temperature.)
4. Record reading of mercury barometer in centimeters of mercury.

Calculations:

1. Determine pressure difference between closed and open end of J tube by subtracting the length of mercury in centimeters in the closed end from the length of the column in the open end. This will be what is known as the gage pressure on the gas in the closed tube.
2. Determine absolute pressure by adding data obtained from calculation 1 to the mercury laboratory barometer reading.
3. Determine the volume of gas in the closed tube by subtracting the mercury level in the closed tube from the reading recorded for the top of the closed end of the J tube.
4. Multiply the data from step 2 by the data from step 3. This should show that $P\ V = k$.
5. Plot on a graph the data from step 2 and 3 above. Plot step 2 data on the vertical axis and step 3 data on the horizontal axis. The curve derived from these plots should be similiar to a portion of the curve shown in your reference text for the Boyle's Law curve.

Analysis and Interpretation:

1. Analyze and discuss any errors between your results and Boyle's Law.
2. Explain what effect a change in temperature during the experiment would have on your results.
3. From reference reading, determine the extremes of temperature and pressure at which Boyle's Law no longer applies. Why?

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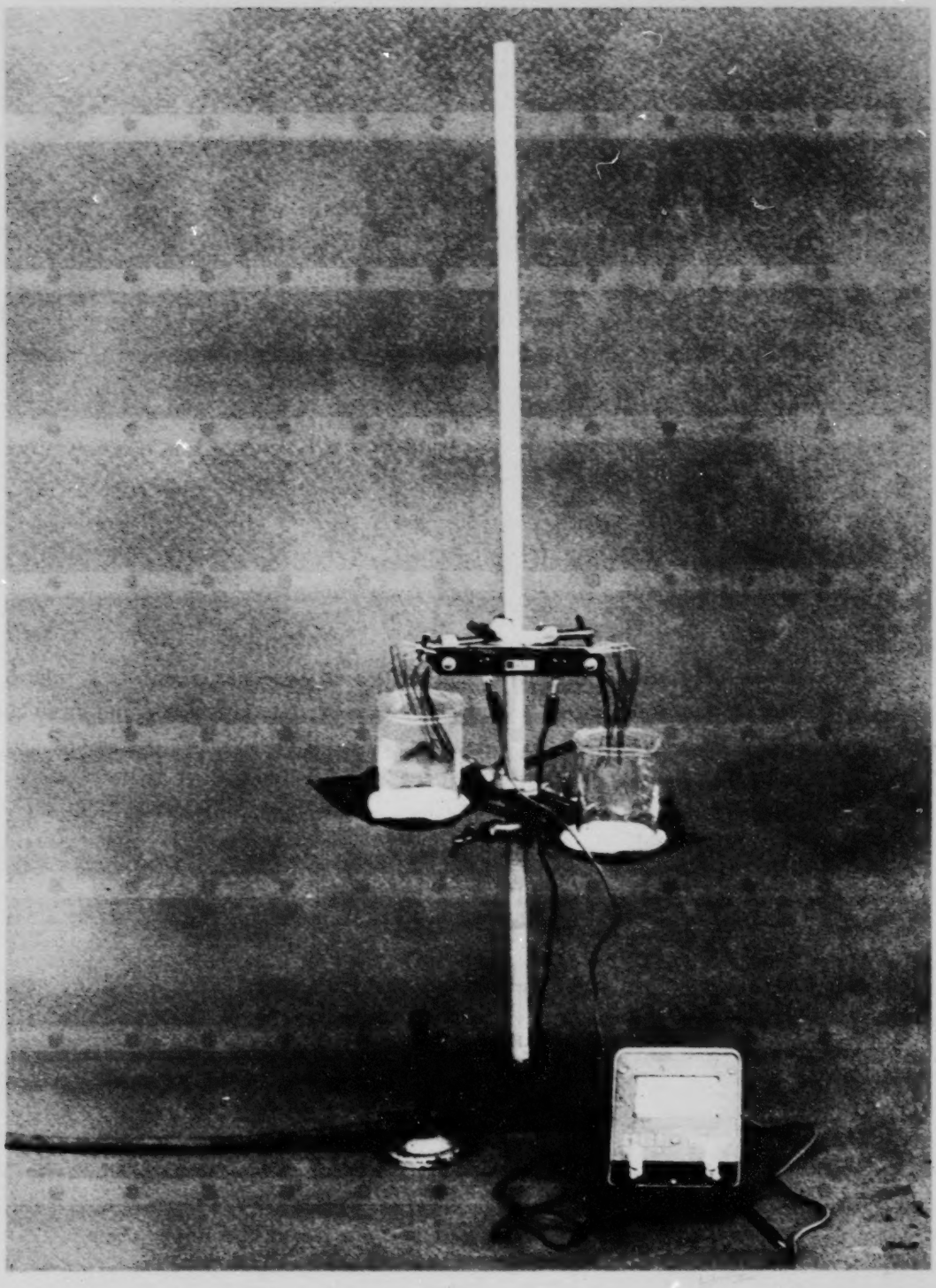


EXPERIMENT VI

Study of the Thermocouple

Purpose:

To study the thermoelectric effect and to plot a calibration chart for a laboratory thermocouple.

Apparatus:

Copper-constantan or glass embedded copper-Kovar; laboratory thermocouple; millivoltmeter (0 to 50 mv); beaker; ice; burner; thermometers (.5°C accuracy); and ring stand.

Information:

If two different metals are placed in contact with each other, they assume a slightly different electrical potential. The difference in potential is due to the motion of free electrons which are present in metals. Free electrons are in rapid and random motion in metallic substances; the electrons in the surface layers will cross the boundry to the other metal. These electrons will pass in one direction much more readily than the other; therefore, one metal is made negative (excess electrons) while the other is made positive (deficient in electrons). For each different pair of metals, the magnitude of the contact potential depends on the temperature at the contact surfaces. The discovery of this effect was made by Volta (1745–1827), but T. J. Seeback (1771–1831) discovered the significant practical application of the variation in contact potential with temperature. Seeback determined that if the two junctions in a closed loop were kept at different temperatures, then the amount of electron current is directly proportional to the difference in temperature between the two junctions. In this experiment the study will be made of the calibration of a junction or thermocouple device as a means of measuring temperature.

Procedure: Laboratory Copper-Constantan Thermopile

1. Set up the thermocouple on a laboratory stand with the cold junction in a beaker of ice and the other end in a beaker of boiling water. Note the materials of which the wires are made. Be sure that enough cracked ice is used to maintain the temperature of the cold junction at 0°C. Record the readings on the thermometers and the millivolt meter.

2. Allow hot beaker to cool while keeping cold junction at 0°C. Record temperature and millivolt meter reading for each drop of 5° C until, with the addition of crushed ice, the beaker containing the hot junction is also brought down to 0°C.

Calculations:

Plot a graph for the copper-contantan thermopile of temperature to millivolts. Plot temperature on vertical axis and millivolts on horizontal axis. Determine millivolt per °C sensitivity.

Analysis and Interpretation:

1. Sketch a face for the millivoltmeter which would read directly in °C and °F.
2. What are some of the practical applications in industry of thermopiles and thermocouples?
3. Analyze the possible sources of error in this experiment.

EXPERIMENT VII

Linear Expansion with Temperature

Purpose:

To study the expansion of materials on being heated and to determine the coefficient of expansion of several metals (aluminum, copper, Kovar and tungsten) and several glasses (lead, soda-lime, and borosilicate).

Apparatus:

Linear expansion apparatus; metal test rods; glass test rods; steam generator; connecting hoses and steam trap (locally fabricated); thermometer .5°C accuracy; burner; and meter stick.

Information:

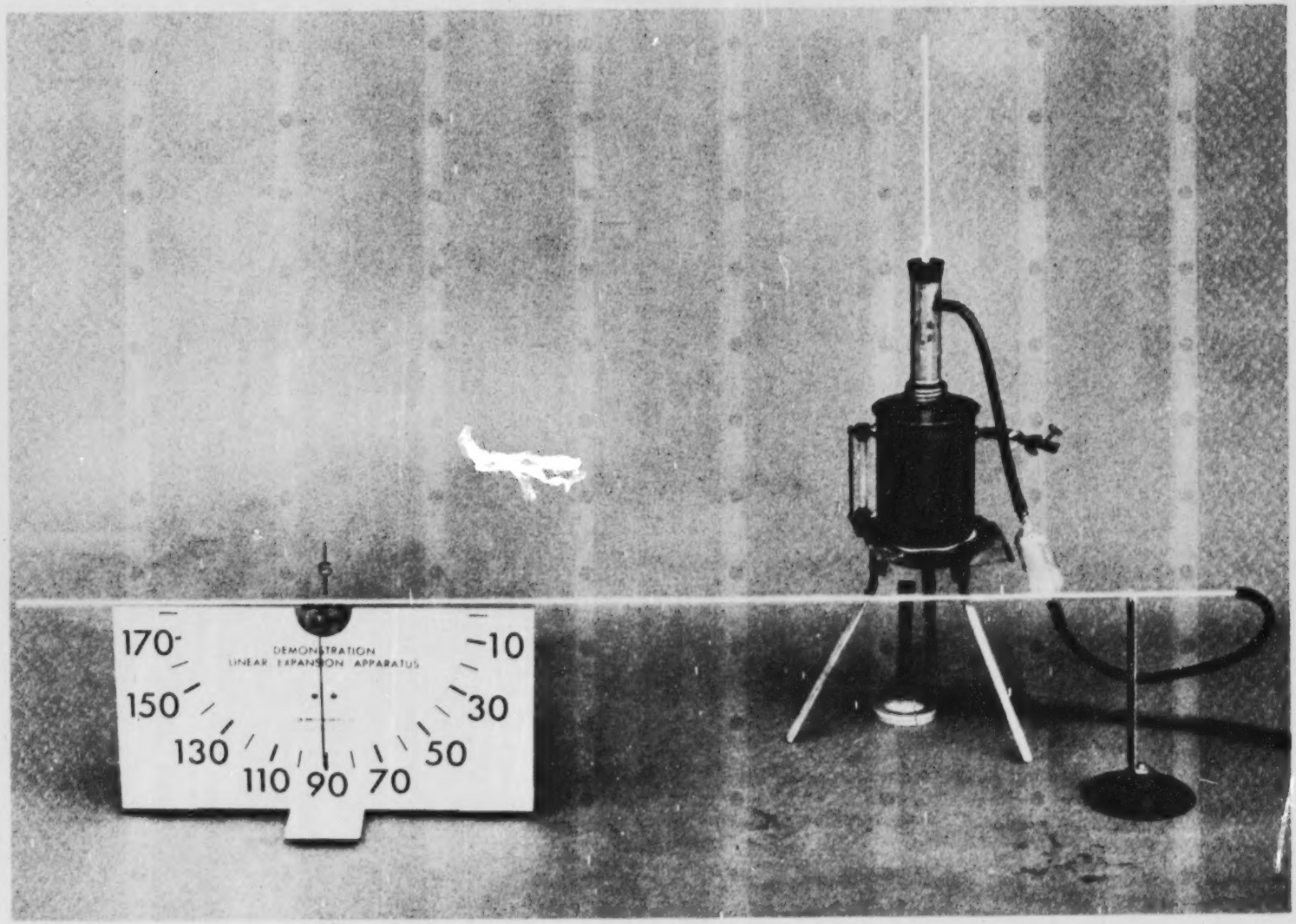
When matter is heated the molecules move further apart, and when cooled, the molecules move closer together. Since gas molecules have the greatest freedom of motion, they expand and contract more than liquids or solids. In general, the freedom of motion and molecular structure determine the amount of expansion and contraction with the temperature. Gases expand the most; liquids are next; and solids follow with the least expansion. There is quite a wide range of action due to difference in molecular structure of different solids.

If solids only are considered here, the student will find wide variation in the amount of change taking place in solids with a change in temperature. The molecules, when heated, tend to spread apart in all directions. In the case of rods or tubing, the main interest lies in the change in length. This relationship of change in length with change in temperature is called linear expansion. All materials expand or contract with changes in temperature, but the amount of these changes depends upon the molecular structure, the original length, and the change in temperature of the material. Since the molecular structure of each different type of solid is unique, there can be obtained by experimentation a coefficient of linear expansion for any given solid which takes into consideration its individual molecular structure. This coefficient of linear expansion α is defined as the change in length per unit of original length per degree change in temperature.

$$\alpha = \frac{L_2 - L_1}{L_1 (t_2 - t_1)} \qquad (1)$$

where:

L_1 = original length
L_2 = new length
t_1 = original temperature
t_2 = new temperature



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When original temperature is higher than the new temperature, the elongation will be negative, which means the solid has contracted rather than expanded.

$$\text{since } e = L_2 - L_1 \qquad (2)$$

$$\text{then } \alpha = \frac{e}{L_1(t_2 - t_1)} \qquad (3)$$

where

e = change in length or elongation

The preceding formula will be used to determine the coefficient of expansion of the solids used in this experiment.

The apparatus used in this experiment uses a friction-driven rotating pointer to indicate the change in length of the sample rod or tube as a deflection of a pointer in angular degrees. The change in length will be calculated from this angular displacement.

$$e = \frac{d\theta}{360} \qquad (4)$$

where:

θ = angular displacement in degrees.

d = diameter of the pointer at the point where the test rod or tube rests on it.

The coefficient of expansion for the rod may be determined with formula 3. Use L_1 as the distance from the fixed stand to the pointer along the tube before heat is applied to the rod.

Procedure:

1. Set up the apparatus as shown in photograph and fill the steam generator two-thirds full of water.
2. Measure and record the length of the rod or tube from the fixed rest to the pointer of the indicator, the diameter of the pointer, the temperature of the rod, and the starting value of θ on the indicator face.
3. Light burner and apply heat to the steam generator until boiler temperature reads 100°. Read and record boiler temperature and θ.
4. Repeat steps 1 to 3 for each test rod.

Calculations:

For each test rod, use formula 3 to determine the coefficient of linear expansion.

Using reference material, compare the laboratory findings with the accepted values and determine percentage of error.

Analysis and Interpretation:

1. What are the possible reasons for error in this report?
2. Give some practical uses for the information from this report in industry.
3. Using laboratory and reference information, design a glass-to-copper seal, glass-to-aluminum seal, glass-to-Kovar, and a glass-to-tungsten seal.

EXPERIMENT VIII

Heating Value of Fuel

Purpose:

To determine the heating value of the laboratory supply, using a continuous-flow calorimeter.

Apparatus:

Continuous-flow calorimeter; thermometer (.1° accuracy); Bunsen burner; gas meter with dial reading accurate to .01 cubic foot; rubber tubing; laboratory balance; and weights.

Information:

Modern industry use many fuels. Some are very common and inexpensive, while others are rare and costly. Fuel oil, coal, natural gas, and bottled gas are examples of low-cost fuels. Alcohol, liquid hydrogen, hydrazine, and nuclear fuels are examples of the more expensive types.

Some fuels are convenient and safe to use and low in air-polluting and solid or particulate residue. Other fuels have to be managed very carefully to prevent explosions, air pollution, and frequent shutdowns for cleaning.

Since in industry air pollution, residue-caused shutdowns and actual fuel costs enter into the profit picture, different industries will call for the use of different fuels.

One of the major items will be fuel cost; therefore, a way must be found to compare the relative cost of fuels. For solid and liquid fuels, this is usually computed in terms of BTU's per pound; in this determination for gaseous fuel, a measured quantity of fuel is used to heat a substance where the heat added can be easily measured. The substance usually preferred is water. Some of the reasons for this are: it is the standard by which both metric and English units of heat are defined and measured, and it has the highest thermal capacity of common substances.

A continuous-flow calorimeter for gaseous fuels allows maximum heat transfer from the flame or heat source to be absorbed by the water.

This calorimeter can be purchased from a laboratory supply house or fabricated from heat-resistant glass as a project for the second-year glass technology student. Water-flow in and out of the calorimeter can be measured and the input and output temperatures may be determined. The water-flow and temperature change must be carefully measured, as well as an accurate measurement of the number of cubic feet of gas used. The heating value of the fuel can be determined by using the basic heat formula

$$H = ms\ (t_2 - t_1) \qquad (1)$$

where:

m = amount of water collected in pounds

s = specific heat of the water

t_1 = water input temperature in °F

t_2 = water output temperature in °F

H = quantity of heat in BTU's

Since the specific heat (s) of water is *one*, the heat absorbed by the burned fuel is

$$H = m\,(t_2 - t_1) \qquad (2)$$

and the heating value of the fuel can be determined.

$$\text{Heating value} = \frac{H}{V} \qquad (3)$$

where H = heat added in BTU's

V = volume of gaseous fuel used in cubic feet

Procedure:

1. Connect the gas tube through the gas flowmeter to the burner. Set up the calorimeter. Be sure that the corks around the thermometer are well sealed to prevent a water leak. Carefully turn on the water to a slow continuous flow. When the water is flowing smoothly, light the burner and adjust it to a low blue flame.

   Place the burner about ½ to ¾ inches below the calorimeter. Adjust water-flow to achieve a 10°F difference in temperature between the input water and output water. While performing this experiment, watch the burner carefully to see that the flame does not go out due to the stack effect of the fire tubes in the calorimeter.
2. When a steady-state condition of water-flow and temperature readings has been reached, start a stop-watch timer and simultaneously read the gas meter, thermometers, and begin catching the output water in at least a quart-size container. Record the length of time to catch water, its weight, gas meter reading at beginning and end of time, and the input and output temperatures.
3. Repeat steps 1 and 2 with a temperature difference of 15°F, 20°F, and 25°F.

Calculations:

Using equations 2 and 3 and the measured data, determine the heating value of the fuel in BTU's/ft.^{3} for each trial. Compare the experimental value with the heating value of the fuel obtained by contacting your local gas company.

Analysis and Interpretation:

1. What are possible sources of error in this experiment?
2. List some of the advantages of natural or manufactured gas as a fuel.
3. What are some of the pollutant products given off to the atmosphere by heat-producing burners and heat engines?

EXPERIMENT IX

Specific Heat of Solids

Purpose:

To study the law of heat exchange and to determine the specific heat of samples of solids, including various types of glass.

Apparatus:

Calorimeter; centigrade thermometer (.1° C accuracy); burner and stand; beaker; centigram balance; metal test samples; and glass test samples.

Information:

The quantity of heat contained in a substance cannot be measured by a direct-reading instrument; it must be measured by its effect on matter.

The easiest effect of heat to measure is a temperature change; but when heat is added to different substances, there is a different temperature change for each substance. Some substances have wide temperature changes with small amounts of heat added. Other substances require large quantities of heat to cause very small temperature changes.

This difference seems to be due to the differences in the molecular structure of each material. This is somewhat confirmed by the fact that the same substances in the different physical states of liquid, gas, and solid, have a different molecular arrangement or bond and require a different amount of heat to cause a change in temperature.

Water as a liquid is the general standard used for heat measurement because water absorbs the greatest quantity of heat for a given temperature change of any common substance. The heat absorbing quality and the fact that water is plentiful and cheap are the reasons it was chosen as the standard.

The units of heat measurement in the English and metric systems defined according to this standard are the British thermal unit and the calorie.

The BTU is defined as the amount of heat necessary to change 1 pound of water 1° Fahrenheit.

The calorie is defined as the amount of heat necessary to change 1 gram of water 1° Celsius. Since the thermal capacity or the ability to absorb heat varies with each substance, a means had to be found to compare each substance to a standard water reference.

This was accomplished by using the ratio of the thermal capacity of a substance to the thermal capacity of water; this ratio is called the specific heat of the substance.

Therefore, specific heat:

$$s = \frac{\textit{thermal capacity of substance}}{\textit{thermal capacity of water}}$$

If the specific heat is used, then the amount of heat any substance will absorb can be determined by the equation shown below.

$$H = ms\ (t_2 - t_1) \qquad (1)$$

where:

m = pounds or grams
s = specific heat of a substance
H = heat (BTU's or calories)
$(t_2 - t_1)$ = temperature change in °F or °C

The specific heat of a substance has no dimensional units so the same value will be used in both the English and the metric system. When the weight is in pounds and the temperature is in °F, the heat units will be calories.

If two or more substances are heated together, then the total heat absorbed is the sum of the heat absorbed by each substance.

At times it will be necessary to mix substances which are at different temperatures. When this occurs the substance at the higher temperature will lose heat and the substance at the lower temperature will gain heat. This action may be written as shown below and is called the law of heat exchange.

Heat lost by hot substance equals heat gained by cold substance.

Water as the standard reference is usually mixed with a substance whose specific heat is to be determined. Since water is a liquid, it will normally need a container to hold it while it is being mixed.

This container is called a calorimeter or calorie meter, and the amount of heat it absorbs must also be considered in writing the equation to determine the specific heat of an unknown material. For a substance mixed in a calorimeter, the law of heat exchange becomes: *heat lost by hot substance equals heat gained by cold substance plus the heat gained by the calorimeter.*

Let:

m_h = mass of hot substance
s_h = specific heat of hot substance
t_h = temperature of hot substance
m_c = mass of cold substance
s_c = specific heat of the cold substance
t_c = temperature of the cold substance
m_{cal} = mass of the calorimeter or mixing cup
s_{cal} = specific heat of calorimeter cup material
t_f = final temperature of mixture and the colorimeter

Then:

$$m_h s_h (t_h - t_f) = m_c s_c (t_f - t_c) + m_{cal} s_{cal} (t_f - t_c) \qquad (2)$$

The m_{cal} s_{cal} is called the water equivalent of the calorimeter. This would be the amount of water which would absorb the same amount of heat as the calorimeter absorbs.

Procedure:

Part I. Specific Heat of Metallic Solids

1. Weigh the calorimeter inner cup to the nearest .01 gram and then fill it with just enough cold tap water so that the specimen will be covered. Record the cold water temperature and the weight of the cup and cold water. Weigh and record the metallic test metal to the nearest .01 gram using the centigram balance. Heat the test metal in a beaker of boiling water for at least 5 minutes; then quickly transfer it to the cold water in the calorimeter cup. Stir gently; read and record the final temperature of the mixture. Take another trial with a different amount of water in the calorimeter cup, using the same metal specimen.
2. Repeat step 1 for each of the test metals.

Part II. Specific Heat of Glass Specimens

1. Repeat step 1 of part I for each of the glass test specimens.

Calculation:

Using equation (2), calculate (for each trial) the specific heat of the metal and glass test specimens. Average the two trials for each substance; then compare this to the reference value. Display your results including percent error in a summary table.

Analysis and Interpretation:

1. Analyze the possible sources of error and describe the steps that could be taken to minimize heat gains and losses from the environment.
2. Explain how the calorimeter minimizes heat gain and losses from:
   a. conduction
   b. radiation
   c. convection
3. List and describe three industrial processes where heat exchange is extremely important.
4. Why is water so widely used as a heat exchange medium in industry?

EXPERIMENT X

Latent Heat and Change of State

Purpose:

To study the change of state process and determine the latent heat of fusion of ice and the latent heat of vaporization of water.

Apparatus:

Calorimeter and stirrer, steam generator; glass laboratory-fabricated steamtrap; burner; thermometers (.1°C accuracy); ice; centigram balance; and rubber tubing.

Information:

Heat energy must be added to a substance to cause it to change from a solid to a liquid, or from a liquid to a gas. This is because the molecules have much greater freedom in a liquid than in a solid; they have extreme freedom in a gas. The opposite is true when going from the gaseous state to the liquid, or from the liquid to the solid; therefore, for this to occur, heat must be removed from the substance. Any material which we find on earth can exist in the liquid, solid, or gaseous state. Sometimes it is difficult to hold the surrounding conditions proper for these changes of states to occur and be repeatable; in other words to have the material go from solid to the gas by adding heat and having it come back to the same form as a solid by removing heat.

In most material, when heat is added or removed and the liquid-gas boundary or the liquid-solid boundary is reached, it is observed that a large number of heat units are involved without a change in temperature of the substance.

When this occurs, the heat which is added or removed is called *latent*, or hidden, heat. Heat which causes a change in the temperature of the substance is called *sensible* heat, since it can be sensed with a thermometer. This experiment will allow the student to observe and measure the amount of heat involved in the change of state process. The point or temperature at which a material changes from a solid to a liquid is called the melting point of the substance; and the heat involved in the change of state is called the latent heat of fusion. The temperature at which a material changes from a liquid to a gas is called the boiling point of the substance; the heat involved in this change of state is called the latent heat of vaporization.

The change of state processes of water will be studied using the law of heat exchange or the so-called method of mixture. When two substances at different temperatures are mixed, the quantity of heat lost by the hot body is equal to the heat gained by the cold body; an equilibrium or intermediate temperature is reached. If this process takes place in such a manner that no heat is gained from or lost to the environment, accurate measurements may be obtained.

The calorimeter construction minimizes heat gains or losses, but increased measurement accuracy can be obtained by taking the following precautions. The temperature range in all the tests should vary equally from the room temperature. The initial cold temperature should be approximately the same amount below room temperature as the final mixture temperature is above room temperature. This will allow the same amount of heat to be lost to the room at the final temperature as is gained by the substance at the cold temperature from the room.

This should cause a heat-loss balance in the experiment. The latent heat of fusion (L_f) will be determined by dropping a few pieces of ice in a calorimeter in which warm water at a known temperature has been placed. As the ice melts the law of heat exchange takes place and the mixture will reach a final equilibrium temperature. The amount of ice used can be determined by weighing the calorimeter cup and its contents after the equilibrium temperature is recorded. Be sure that the ice has been out of the freezer long enough to reach its melting point of 0° C or 32°F. The latent heat of vaporization (L_e) will be determined by passing steam through a known amount of cool water. The steam condenses in the cool water, and the mixture reaches a final equilibrium temperature. The heat absorbed by the thermometers should also be considered in the experiment.

Instead of going into the mass and specific heat of the thermometer material, simply use an approximate water equivalent for the thermometer of about 0.5 grams of water. The working equations for the law of heat exchange in this experiment are:

Part I. Latent Heat of Fusion (L_f)

Heat gained by the ice = Heat lost by the water and heat lost by calorimeter cup and heat lost by the water equivalent of the thermometer.

$$M_i(L_f) + M_i(t_f - t_i) = M_w(t_w - t_f) + M_c s_c(t_w - t_f) + W.E.(t_w - t_f)$$

or

$$L_f = \frac{(M_w + M_c s_c + W.E.)\ (t_w - t_f) - M_i\ (t_f - t_i)}{M_i}$$

where:

M_i = mass of the ice

M_w = mass of the water

M_c = mass of the calorimeter cup

s_c = specific heat of the calorimeter cup

$W.E.$ = water equivalent of the thermometer

t_i = temperature of the ice

t_w = temperature of the water

t_f = equilibrium temperature in the calorimeter

L_f = latent heat of fusion (water)

Part II. Latent Heat of Vaporization (L_e)

$$M_s (L_e) + M_s (t_s - t_f) = M_w (t_f - t_w) + M_c s_c (t_f - t_w) + W.E. (t_f - t_w)$$

or

$$L_e = \frac{(M_w + M_c s_c + W.E.) (t_f - t_w) - M_s (t_s - t_f)}{M_s}$$

where:

M_w	=	mass of cool water in calorimeter
M_s	=	mass of steam added
M_c	=	mass of calorimeter
s_c	=	specific heat of calorimeter
t_w	=	initial temperature of cool water and calorimeter cup
t_s	=	temperature of steam
t_f	=	equilibrium temperature in calorimeter
L_e	=	latent heat of evaporization (water)
$W.I.$	=	water equivalent of thermometer

Procedure:

Part I. Latent Heat of Fusion (L_f of Water)

a. Weigh the calorimeter cup and stirrer accurately and note the specific heat of the material from which it is made.
Record the weight of cup and stirrer. Fill the cup about half full of water whose temperature is about 10°C above room temperature. Weigh water, cup, and stirrer combination and then place in calorimeter outer cup. Record the weight of water, cup and stirrer combination. Select several pieces of ice, dry each carefully with a paper towel and drop into water in the cup. Add ice and stir mixture slowly until all ice is melted and the final equilibrium temperature in the cup is about 10° below room temperature. Record the final temperature, then weigh and record the weight of the calorimeter cup and its contents.

b. Repeat Part I a to give three complete sets of readings.

Part II. Latent Heat of Vaporization (L_e) of Water.

a. Weigh the calorimeter cup and stirrer accurately and note the specific heat of the material from which it is made. Record the weight of the cup and stirrer. Fill the inner cup about three-quarters full of water whose temperature is 10°C to15°C below the room temperature. Weigh water, cup, stirrer

combination. Record this weight. Place hose from steam generator into top of calorimeter and bubble steam into the water until the temperature of the water is raised to 40°C, or 15°C above room temperature. Remove steam tube from calorimeter, record thermometer reading as final or equilibrium temperature. Remove inner cup filled with water and the stirrer from the outer calorimeter cup. Weigh and record the weight of the inner cup and its total contents.

b. Repeat Step 2a until three complete sets of readings are obtained.

Calculations:

Part I. Latent Heat of Fusion of Water

Use the data recorded in the procedure section, Part Ia and Ib, and determine M_c, M_w and M_i. From this information and the temperature readings, determine the latent heat of fusion (L_f) for each of the three trials. Average the final results of these three calculations and compare it to the standard reference value of the latent heat of fusion of water.

Part II. Latent Heat of Vaporization of Water

Use the data recorded in the procedure section, Part IIa and IIb, and determine the M_c, M_w and M_s. From this information and temperature readings, determine the latent heat of vaporization (L_e) of the steam for each of these three calculations and compare their average to the standard reference value of the latent heat of vaporization of water.

Analysis and Interpretation:

1. Determine the percent error between your results and those from the standard reference for the latent heat of fusion and the latent heat of vaporization.
2. Describe some steps which may be taken to minimize the error in this experiment.
3. What are some of the applications to the glass industry of the type of information gained from this experiment?

EXPERIMENT XI

Velocity of Sound by Resonance Methods

Purpose:

To use glass apparatus in the measurement of sound characteristics.

Apparatus:

Water resonance tube, air resonance tube, tuning forks, striking block or hammer, rosin and chamois cloth.

Information:

The most direct method of measuring the velocity of sound through a material would be to station two groups a mile or so apart with visual contact between the groups. This is not practical due to size limitations of the usual laboratory. So in the laboratory we will have to use a different method, and we will use the phenomenon called resonance to do so.

Every object can be made to vibrate. An object will vibrate at its natural frequency, which depends upon its size, shape, and molecular structure. If two bodies having the same natural frequencies are set close to each other, and one is made to vibrate, then the other will start to vibrate also. This is called sympathic vibration, and the transferring of the energy from the first to the second object is called resonance. You may have encountered this phenomenon when a piece of chinaware or glassware was set into resonant vibration by a musical note played nearby. All wind-type musical instruments are based on resonance – a certain length of the air column will vibrate at a certain pitch (frequency) when the reed or lip vibrates at the proper rate.

The fundamental equation of wave motion used in this experiment is:

$$V = n\lambda$$

where:

V = Velocity of propagation of the wave

n = Number of complete waves per second

λ = Wavelength – the distance the wave travels in the medium under study in the time for a single vibration to occur.

Resonance will be used to determine the velocity of sound in both air and solid rods.

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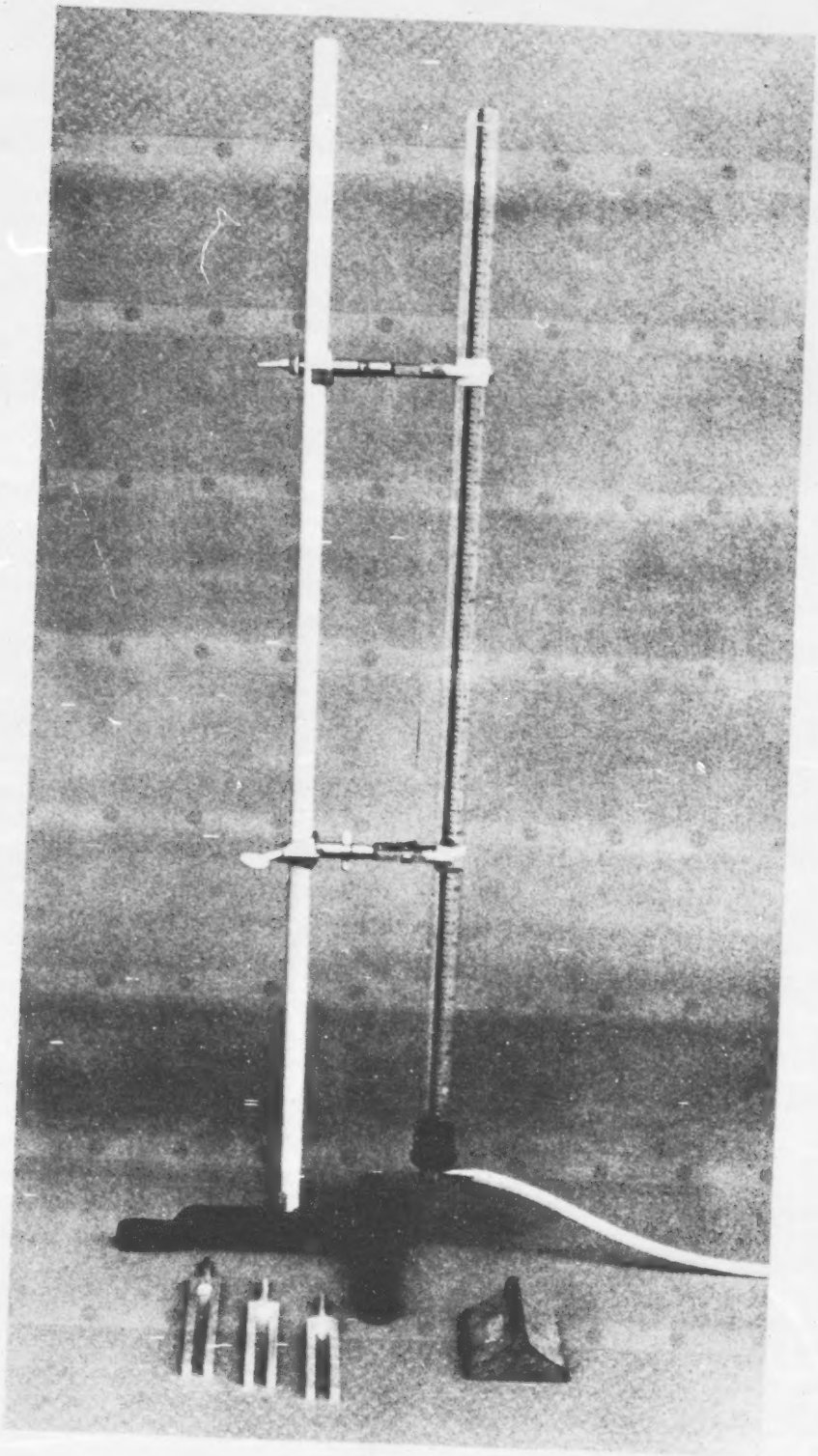

Part I. Velocity of Sound in Air

A tuning fork held over the top of a column of air in a tube with one end closed will cause vibrations to be sent through the air in the tube and reflected from the bottom to return again to the top. If the length of the column of air at the top of the tube is adjusted to a length equal to one-fourth the wavelength of the tone from the fork, then the sound returned will be in phase with the original tone and will produce a marked increase of volume. This is one of the evidences of resonance and will occur whenever the tube is an odd multiple of this original one-fourth wavelength, such as 1/4, 3/4, 5/4, etc. The apparatus used in this portion of the experiment can be fabricated in the glass shop from a glass tube approximately 1 inch in diameter and 4 feet long. This glass tube will use a one-hole stopper and a small 90-degree glass elbow attached to a rubber or plastic hose. The hose will be attached to a beaker or container of at least 1000ml., with a hose connector fused in the bottom. The water level in the 4-foot tube – and thus the length of the air column – will be controlled by vertically raising and lowering the beaker or container with respect to the water in the tube.

Part II. The velocity of sound in a metal rod will be measured by causing the rod to vibrate at its natural frequency. When this rod is vibrated at its natural frequency in a 4-foot glass tube closed at one end by a solid rubber stopper, standing or resonance waves will be set up in the air column within the tube. If cork dust is sprinkled within the tube, it will line up in alternate concentrations and rarifications as a direct result of the vibrating air column.

The apparatus used in this experiment can be partially fabricated in the glass shop. The metal rods with end plates and mounting stand will have to be fabricated in the wood or metal shop.

The operation and measurements in this experiment depend upon the fact that a metal rod clamped in the middle and stroked with a rosined chamois cloth will set up longitudinal vibrations which can be transferred to the air column in the glass tube. The basic wave formula will be used in this portion of the experiment as follows:

$$V_m = n\lambda_m$$
$$V_a = n\lambda_a$$

(Since the sound is introduced into the air by the metal rod, then n is the same for both air and metal.)

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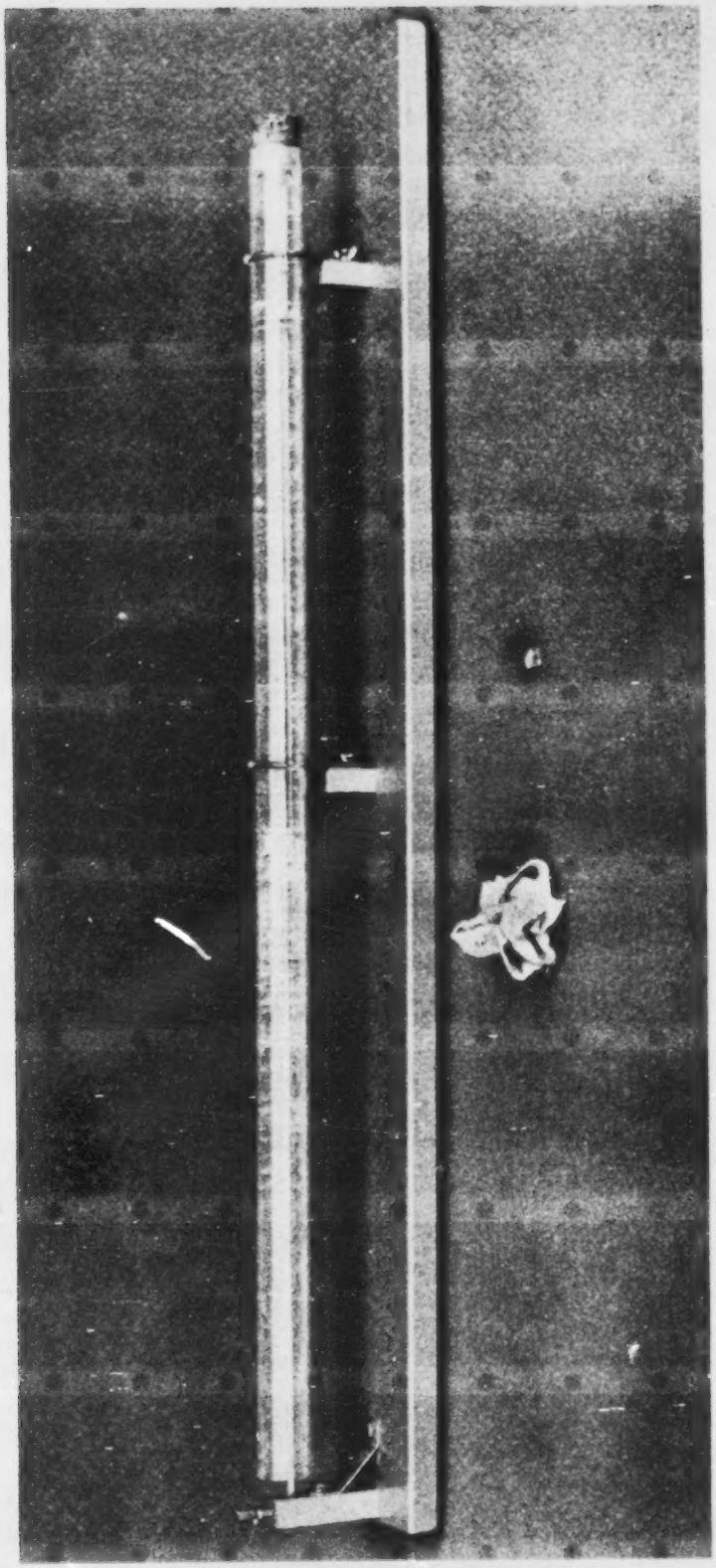


where:

V_m = velocity of sound in metal in ft/sec.
V_a = velocity of sound in air in ft/sec.
n = frequency of note generated
λ_m = wavelength of sound in metal in feet
λ_a = wavelength of sound in air in feet

Therefore:

$$\frac{V_m}{V_a} = \frac{n\lambda_m}{n\lambda_a}$$

or

$$V_m = \frac{V_a \lambda_m}{\lambda_a}$$

Let L = length of rod in feet

The natural vibration of the rod will produce a wavelength equal to twice the length of the rod. That is,

$$\lambda_m = 2L$$

Then

$$V_m = \frac{V_a\, 2L}{\lambda_a}$$

The velocity of sound in air has been found to be:

$$V_a = 1087 \text{ ft/sec.} + 1.1\,(t-32) \text{ ft/sec.}$$

where t = existing temperature in °F

Procedure:

Part I. Velocity of Sound in Air

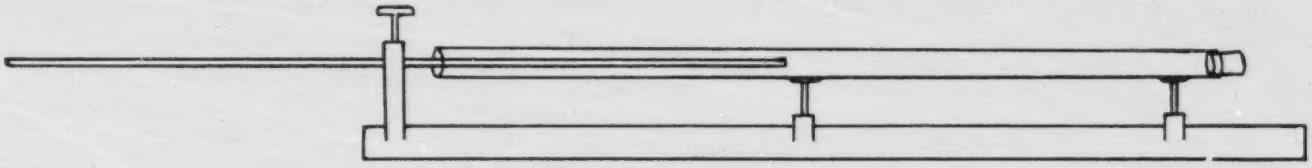
a. Set up the 4-foot glass resonance apparatus fabricated in the glass shop. Fill reservoir with water and elevate it until the water fills the tube approximately 2/3 full. Strike the tuning fork on the strike pad and place it at the open end of the tube, being careful that the vibrating tuning fork does not strike the glass tube. With the vibrating tuning fork over the tube, raise and lower the water level until the first resonance point is reached. Record the length of the air column for that tuning fork. Repeat the above instructions until the second resonance and third resonance points are reached. Record the second resonance point as three-quarter wavelength and the third point as five-quarter wavelength for the tuning fork.

b. Measure and record the temperature of the air in the room.

c. Repeat steps Ia and Ib for each tuning fork used.

Part II. Velocity of Sound in Metal Rods

a. Assemble base, metal rod, and the 4-foot tube fabricated in the glass shop. Sprinkle dry cork dust lightly on the inside of the glass tube. The metal rod should be inserted into the tube and the end of the rod pulled back through the metal post. Adjust the metal rod so that it is clamped halfway along its length by the screw mounted in the metal post. Half of the rod will be in the tube, and the other end free on the other side of the metal clamp.



Add a small amount of rosin to a chamois cloth and stroke the rod with a quick, firm stroke until vibrations are set up. These will cause dust patterns in the glass tube. Measure and record the distance between any two minimum points in the dust pattern, and record the total length of the metal rod.

b. Measure and record the temperature of the air in the room.

c. Repeat steps IIa and IIb for each type of rod used.

Results:

Part I. Using measured data from the water-air resonance tube, determine the velocity of sound in air for the room. Compare the experimental value with the calculated value for the air at recorded room temperature.

Part II. Use the measured data from the air tube and metal rod to calculate the velocity of sound in each metal rod. Compare the experimental results with accepted values from reference tables.

Analysis:

1. What are some of the possible sources of errors in this experiment?
2. Explain how it could be theoretically possible for a sound to break a piece of glass apparatus. Would the same sound frequency have the same effect on all glass apparatus?

EXPERIMENT XII

Photometry and Illumination

Purpose:

To determine the candle-power rating and light distribution from various types of glass-enclosed light sources.

Apparatus:

Optical bench; bunsen photometer; standard lamp; test lamps; 15W, 40W, 60W, 100W frosted and clear glass bulbs; photoelectric foot-candle meter; and black screen for shielding outside light.

Information:

The use of glass in the lighting industry is one of the major uses of this product. The scientific glassblower today does not hand-blow glass bulbs, but the transmission of light through various types of glass used in this industry is of interest to the glass student. In this study the definitions of some of the basic terms are essential in the study of photometry and illumination.

1. The intensity of light source (I). – Unit of measurement is the candle power and was originally based on the light emitted by a standard candle. One square centimeter of the surface of melting platinum gives off sixty candlepower and is the primary standard reference used today. The candlepower unit is used in working with light *sources*.

2. The intensity of illumination (E). – Measurement unit is the foot-candle and is only used in measuring light at a *surface which is not a source*. One foot-candle is the intensity of illumination on a surface one foot away from a one-c.p. source when the light rays are perpendicular to the illuminated surface.

$$E = \frac{I}{d^2}$$

where:

E = illumination in ft-c
I = intensity in candlepower
d = distance from surface to the source of light

or

$$E = \frac{I \cos \theta}{d^2}$$

if the light rays are not perpendicular to the surface and θ is the angle between the light ray and a line which is perpendicular to the surface.

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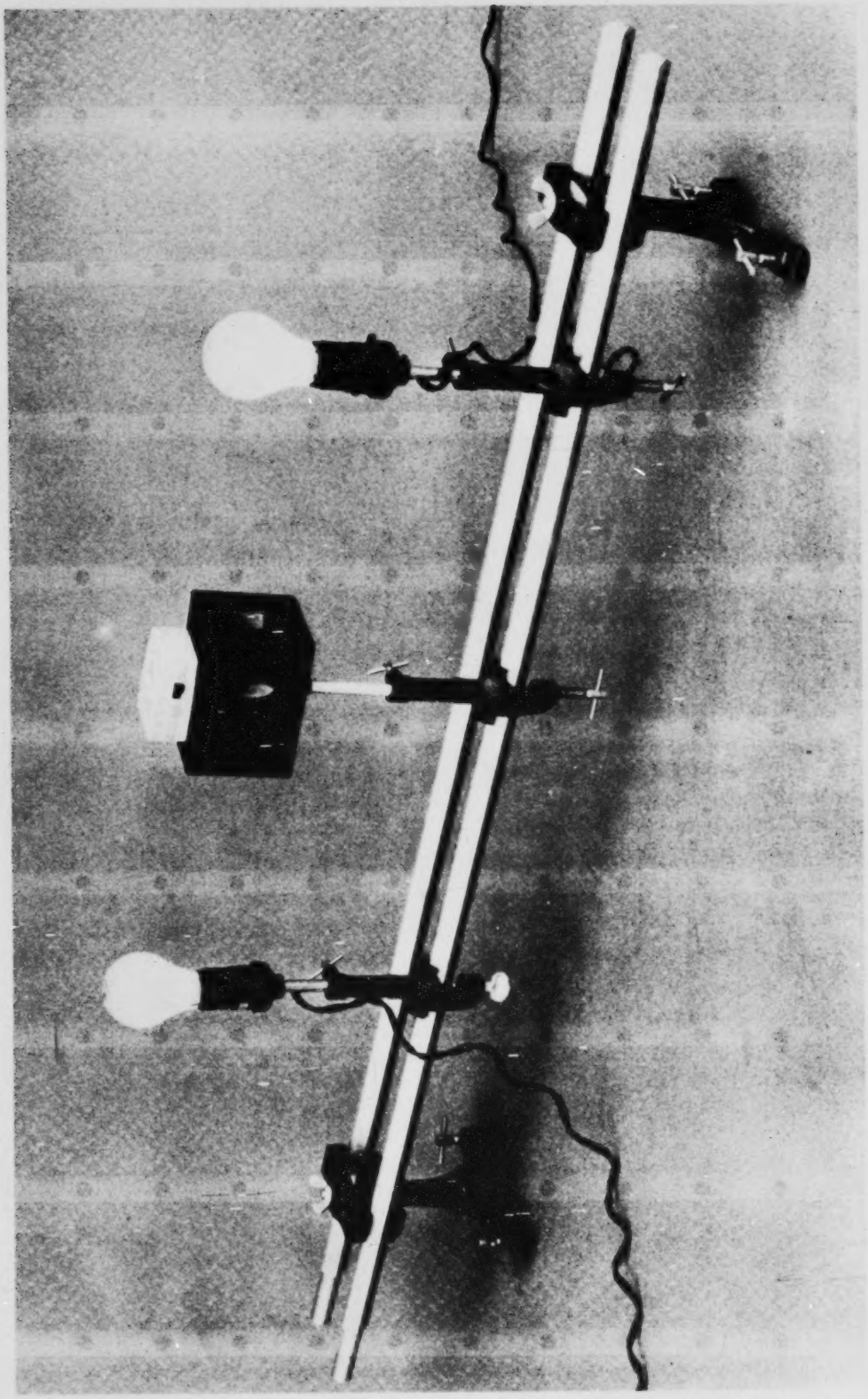

3. Flow of light energy, or flux (F). – The total light energy is the intensity of illumination at a surface times the area of the surface.

$$F = EA$$

or the flux output from a light source is

$$F = 4 \pi I$$

where the measurement unit for flux is lumens.

Measuring the light intensity of a source. – Light intensity from a source is measured by comparing the illumination a source causes to the illumination from a standard source, where the illumination in footcandles of both sources is the same and the light rays are striking perpendicular to the surface. When this occurs, then the following formula may be derived and used for comparing the candlepower of a standard lamp and a test lamp.

$$E_t = E_s$$

where: E_t = illumination in foot-candles of test lamp
E_s = illumination in foot-candles of standard lamp

Since $E_t = \frac{I_t}{d_t^2}$ and $E_s = \frac{I_s}{d_s^2}$

$$\frac{I_t}{d_t^2} = \frac{I_s}{d_s^2}$$

or

$$\frac{I_t}{I_s} = \frac{d_t^2}{d_s^2}$$

where:

I_t = candlepower of test lamp

I_s = candlepower of standard lamp

d_t = perpendicular distance from test lamp to illuminated surface

d_s = perpendicular distance from standard lamp to the illuminated surface

The foot-candle meter may also be used in determining surface illumination and then by calculation the candle-power of a light source may be determined. The heart of the foot-candle meter is a photoelectric cell that converts light energy to electrical energy which can be read on an electric meter calibrated in foot-candles of illumination. The electricity generated is directly proportional to the amount of illumination reaching the surface of the photoelectric cell.

Procedure:

Part I. Source Intensity of Test Lamp.

a. Set up the standard lamp, first test lamp and bunsen photometer on the optical bench. Adjust the position of the photometer between the test and standard lamps for equal illumination on both sides of the screen. Be sure that all excess outside light is screened from the photometer and that equal illumination is carefully checked. Record the intensity of the standard lamp (I), the distance from the standard lamp to the photometer (d_s), and the distance from the test lamp to the photometer (d_t).

b. Set up the photoelectric meter to give a reading of about 40 footcandles of illumination from the test lamp. Be sure that excess outside light is screened from the meter and record the perpendicular distance from the test lamp to the face of the meter as (d_m).

c. Repeat Steps Ia and Ib for each test lamp used.

Part II. Check the validity of the formula $E = I \cos \theta / d^2$ by setting up a standard lamp so that the light rays from it strike the face of the photoelectric meter at an angle and cause a reading of about 30 footcandles on the meter. Record the straight-line distance (d) of the standard lamp to the face of the photometer and the angle (θ) between the light rays and a line perpendicular to the face of the photoelectric meter.

Part III. Use the photoelectric meter measure the illumination at various work areas:

1. reading area
2. laboratory
3. glass shop
4. office area

Results:

Part I. Calculate the candlepower of each test lamp using the data from bunsen photometer readings and the data from the photoelectric meter. Chart and compare the candlepower values from two sources.

Part II. Verify $E = I \cos \theta / d^2$ from the data recorded with the light rays at an angle to the photoelectric meter surface by solving for the candlepower of the standard lamp.

Part III. Compare your readings for the illumination values at various work areas with the recommended values as found in the literature.

Analysis:

1. Compare the output of clear and frosted glass bulbs of the same wattage. What are the different types of bulbs used?
2. With the aid of outside reading, give a brief history of the lighting industry and the glass blowers part in this history.

EXPERIMENT XIII

Study of Spherical Mirrors

Purpose:

To study image formation by curved spherical surfaces and to determine the radius of curvature of a concave and convex mirror.

Apparatus:

Optical bench; concave and convex surfaces; screen; light source with object plate; and vernier calipers and spherometer.

Information:

In studying image formation, it is convenient to think of light rays as being straight lines of light propagation. A light ray is considered to be perpendicular to the wave front of the electromagnetic disturbance. The wave theory of light will be used in our discussion of image formation.

The apparatus for this experiment calls for a convex and a concave surface. These surfaces may be purchased through a scientific glass house or may be ground by the glass technology student as a project in his scientific glass technology program.

In studying the image formation by curved spherical surfaces, several assumptions will be used. These are:

1. All light rays which approach the surface parallel to the principal axis are reflected back through a common point on the axis known as the focal point. (This is only true though for rays very close to the principal axis.)
2. A light ray which approaches the surface through the center of curvature will be reflected directly back on itself.
3. A light ray which passes through the focal point on its way to the surface will be reflected back parallel to the principal axis of the surface. (This is true only for light rays close to the principal axis.)

The law of reflection of light will be used in this experiment. This law states that the angle of incidence is equal to the angle of reflection. The angle of incidence is the angle between the incident ray and a line perpendicular to the surface at that point.

The three cases of ray incidence discussed above will be used in determining the location of the image formed by a curved surface. If the image is on the same side of the mirror as the object, reflected light rays will actually pass through it and it is called a real image. If the image is on the opposite side of the curved surface from the object, the light rays only appear to pass, but do not actually pass through the image, and it is called an imaginary image or virtual image.

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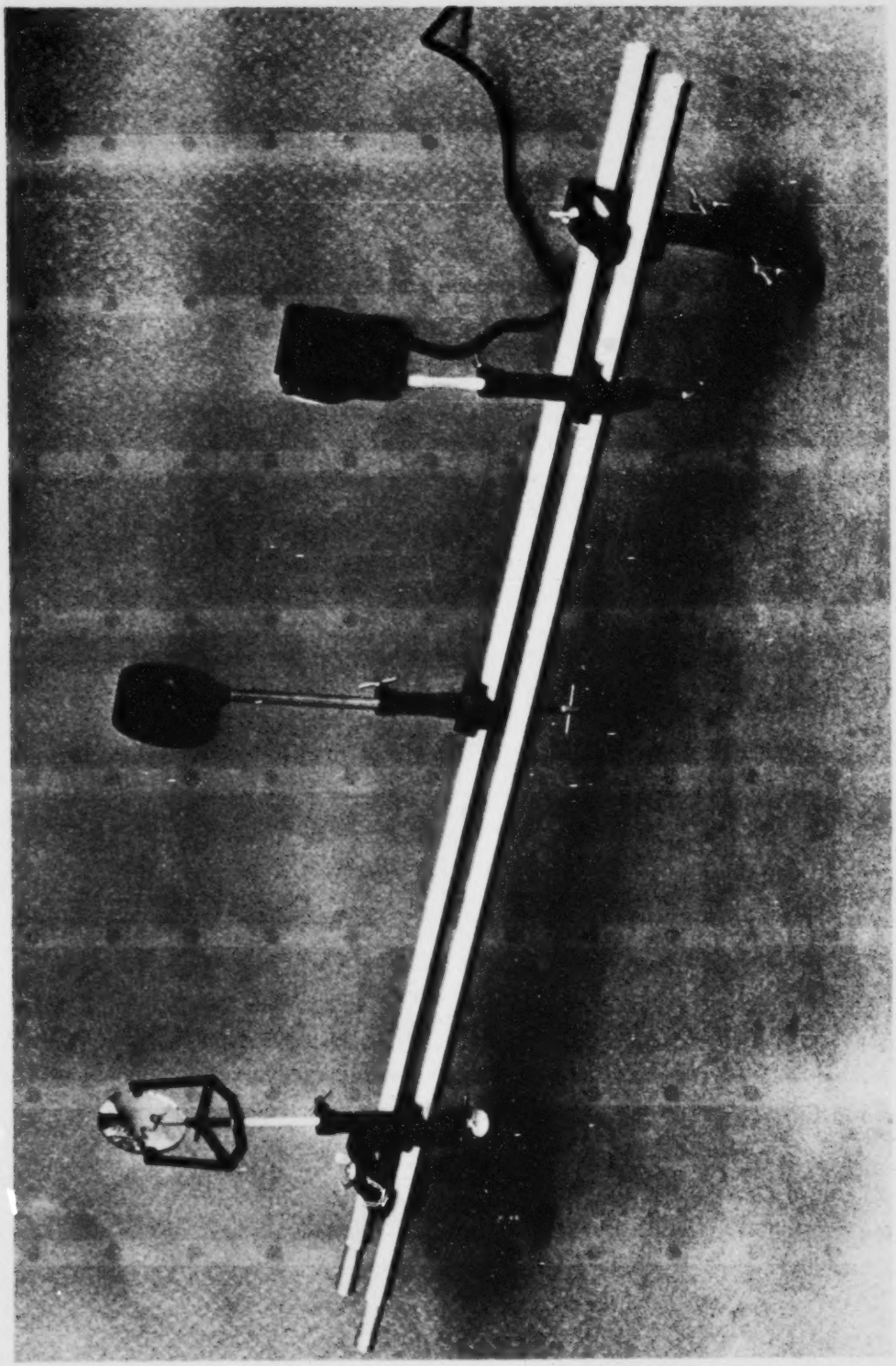
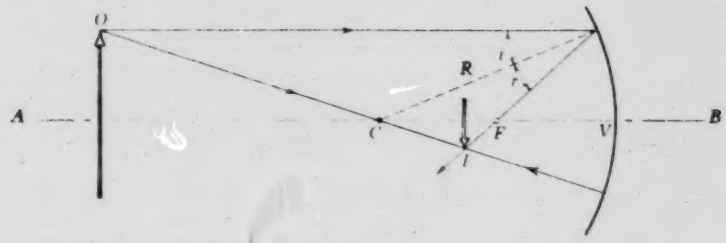




The terms involved with curved surfaces are shown below:

AB = the principal axis
V = the vertex or surface center
O = the object
I = the image
C = the center of curvature
F = the principal focus
R = the radius of curvature of the surface

For curved surfaces that are small compared with the radius of curvature, the principal focus lies about halfway between the center of curvature and the vertex. Or we may say

$$R = 2f$$

The relationship between object distance, image distance, and focal length is

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

where:

d_o = the distance the object is away from the vertex
d_i = the distance the image is away from the vertex.
f = the distance the principal focus is from the vertex

The focal length is (+) if it is in front of the mirror and (−) if it is behind the mirror. A real image which is in front of the mirror will have an image distance (d_i) which is (+) and an imaginary or image behind the mirror will have a (−) image distance.

Methods used in determining radius of curvature:

1. Concave mirror. If an object is set at a distance from the concave surface so that a real image is formed at the same point as the object, then the object distance is equal to the image distance; and the object distance is equal to 2 times the focal length. The object is then at the center of curvature of the surface.
2. Radius of curvature using a spherometer. The peg spherometer used in this experiment consists of a flat metal base with three equally spaced legs of identical length and a micrometer screw at the center. The legs form a flat plane and the micrometer screw can be adjusted above or below the plane of the legs. (A spherometer is shown in the illustration on page 52.)

With this spherometer, let (L) be the average distance between the legs and (d) be the micrometer screw reading above or below the plane of the legs when it is resting on the curved surface. In this case then:

$$R = \frac{d}{2} + \frac{L^2}{6d}$$

Procedure:

Part I. Image Formation by and Radius of Curvature of a Concave Surface

Set up the optical bench with concave mirror, object, light source and screen.

Determine the location, object distance and image distance, when the object is placed at:

a. Maximum distance from curved surface.
b. Further away from the screen than the center of curvature of the surface.
c. At the center of curvature of the surface.
d. Between the center of curvature and the focal point.
e. At the focal point.
f. Between the focal point and the curved surface.

Note the relationship between image and object size, and whether there is a real or virtual (imaginary) image in each of the above trials.

Part II. Image Formation by a Convex Surface

Set up optical bench as in part I, except use a convex surface instead of concave. Observe the location of the images as in part I, a through f.

Part III. Radius of Curvature by Use of the Spherometer

Measure both the concave and convex surfaces with the spherometer. Record for each surface the measured value of (d) and (L).

Results:

Part I. Show by graphical representation the ray diagrams of the images formed, image location, and relative size of the object and image for trials Ia through If of the measurements section.

Determine by calculations the location of the center of curvature of the surface, using measurements obtained in steps Ia, Ib, and Ic.

Part II. Sketch, from observations in (a) through (f) of the measurements in part II, the ray diagrams showing location of image and object for the convex surface.

Part III. Determine the radius of curvature of the concave and convex surfaces, using the information obtained from the spherometer measurements.

Analysis:

1. Summarize and compare the results from the several methods of determining the radius of curvature of spherical surfaces.
2. Explain any inherent sources of error in the image location studied in this laboratory and discuss methods normally used to overcome these difficulties.
3. What are some of the practical applications of the concave surface mirror?
4. Are there any practical uses for the convex surface mirror?

EXPERIMENT XIV

Index of Refraction

Purpose:

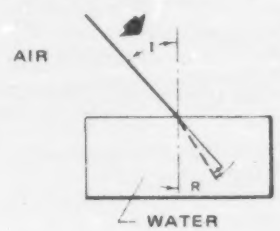
To study the refraction of light in various types of glass and to verify Snell's law of refraction.

Apparatus:

Rectangular glass plate, borosilicate, soda lime, lead glass, and a triangular glass prism.

Information:

The bending of light rays as they pass from one medium to another is the subject of study for this experiment. This bending of light at the boundary between two different mediums is called refraction. Refraction or medium-face bending is caused by the change in the speed with which light travels through the two mediums. Light travels at its greatest speed in a vacuum and only slightly slower in the gases of our atmosphere. The speed of light is reduced as the material becomes optically dense. Water and glass of all types are optically more dense than air. You may have observed that when a light ray strikes an object perpendicular to the surface, there is no bending of its rays; but if a light ray strikes the surface at an angle away from the perpendicular, the part of the light which is not reflected will enter the surface and will be bent. The amount of the bend of the light ray is proportional to the ratio of the velocities of light in the two mediums.



If the ray is traveling from a less dense to a more dense medium, the refracted angle will be smaller than the incident angle. The incident angle is the angle between the entering ray in the new medium and a line perpendicular to the surface. When the ray is traveling from a less dense medium to a more dense medium, it will be bent towards the perpendicular or normal line. When the ray is traveling from a more dense to a less dense medium, the ray will be bent away from the perpendicular or normal line.

The Dutch physicist Snell found that, when light travels between any two mediums, regardless of the striking angle, the ratio of the sine of the refracted angle to the sine of the incident angle is a constant. It turns out that this constant is also the ratio of the velocity of light in the incident medium to the velocity of light in the refracting medium. This constant is called the *index of refraction* and the Greek letter μ is used as its symbol.

$$\mu = \frac{\sin i}{\sin r} = \frac{V_1}{V_2}$$

where:

i = angle between incident ray and the normal line.

r = angle between refracted ray and the normal line

V_1 = velocity of light in the incident medium.

V_2 = velocity of light in the refracting medium.

Procedure:

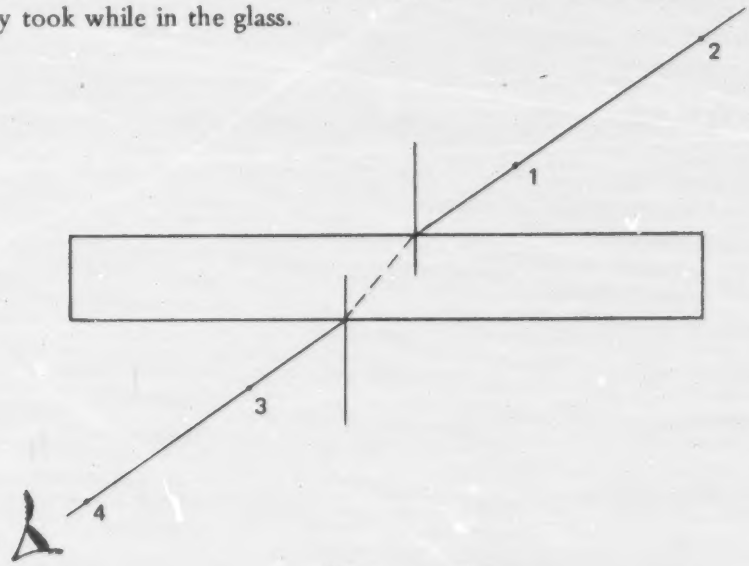
Part I. Rectangular Glass Plate.

Place a piece of graph paper on a cork or cardboard back. Set the rectangular glass plate near the center. Outline the glass plate on the graph paper as in the illustration below. Set pins 1 and 2 in line with each other in the upper right-hand side of the graph paper, but at an oblique angle to the glass surface. From the lower left-hand side of the graph paper, position the eye so that pins one and two appear to be in line when viewed through the glass. Place pins 3 and 4 on the lower left side of graph paper so that they are in line when viewed through the glass with pins 1 and 2.

Draw a line through pins 1 and 2 to the surface of the glass. Draw a line through pins 3 and 4 to the surface of the glass.

Construct a line perpendicular to the surface of the glass at the point of intersection with line 1–2 and the glass surface.

Construct a line perpendicular to the glass surface at the point of intersection between the line 3–4 and the surface. Now draw a line between the two intersections points, within the glass rectangle. This will represent the path the light ray took while in the glass.



The rays of light came to our eye from pins 1 and 2, through the glass, and through pins 3 and 4.

Measure and record the angle in degrees between line 1–2 and the perpendicular line at its point of intersection with the surface. Call this incident angle 1. Record the angle between the line drawn inside the glass frame and the above perpendicular line. Call this refracted angle 1. Measure and record the angle between the line drawn inside the glass area and the perpendicular to the surface at its intersection with line 3–4. Call this incident angle 2. Record the angle between line 3–4 and the perpendicular at the intersection point. Call this refracted angle 2. Note that the angle is smaller when light is going into a more dense medium and is larger when going to a less dense medium.

Repeat the above procedure for the other two types of glass.

Part II. Refraction in a Triangular Glass Prism.

Place a triangular glass prism in the center of a sheet of graph paper with its base parallel to the horizontal edge of the paper. Outline its position on the graph paper with a sharp pencil. Insert a pin near the upper left corner of the paper. Place a second pin a couple of inches away from the first in such a manner that a line drawn through the two pins will strike the glass surface at a sharp angle and to the left of the center of the glass. With your eye close to the lower right side of the paper, move your line of vision from left to right until both pins appear to be directly in line. Mark this line of sight by placing a third pin in the lower right-hand side of the paper so that it appears, while looking through the glass, to be directly in line with the other pins. Place a fourth pin in line with and on the same side of the paper as the third pin. Check carefully, when sighting down the two pins from the lower right corner of the paper and through the glass, that all four pins appear to form a straight line. Mark carefully on the paper the position of each pin.

Remove the glass plate and draw a straight line through pin positions 1 and 2 until it strikes the glass surface. Draw a straight line through pin positions 3 and 4 until it strikes the glass surface. Connect the two points of intersection with a line. Call this line 1.

Now place two pins, one on each side of the prism and touching the prism, such that a line drawn between them would be parallel to the prism base. Look through the prism with the eye close to the paper while moving your head back and forth until the two pins appear to be in line with each other. Place a third pin on the opposite side of the prism from the eye so that the three pins appear to be in a straight line when viewed through the prism. Place a fourth pin on the same side of the prism as your eye that will appear to be in a straight line with the other three when viewed through the prism.

Be sure an outline of prism has been made and the four pin positions have been marked. Remove prism. Draw an external line connecting the two pins on either side of the prism to each other. Construct the line between the pins that were touching the prism. Call this line 2. This is approximately the path that this light ray would take through the prism.

Repeat part II for triangular prisms made from the other types of glass.

Results:

Part I. Glass Plate

Compute the index of refraction of each of the glass plates, using the formula given in the body of this experiment, and using incident angle 1 and refracted angle 1.

Do the same by using incident angle 2 and refracted angle 2.

Part II

Diagram and then label path of incoming and outcoming light rays from trangular glass prisms.

Analysis and Interpretation:

1. Compare the refractions indexes found in the experiment with those from published tables.
2. From outside reading, explain why the white light is spread out into the spectrum colors.
3. Diagram, using colored pencils, the separation or dispersion of light.
4. What is the importance of the index of refraction of particular kinds of glass in the manufacture of optical instruments and lenses?

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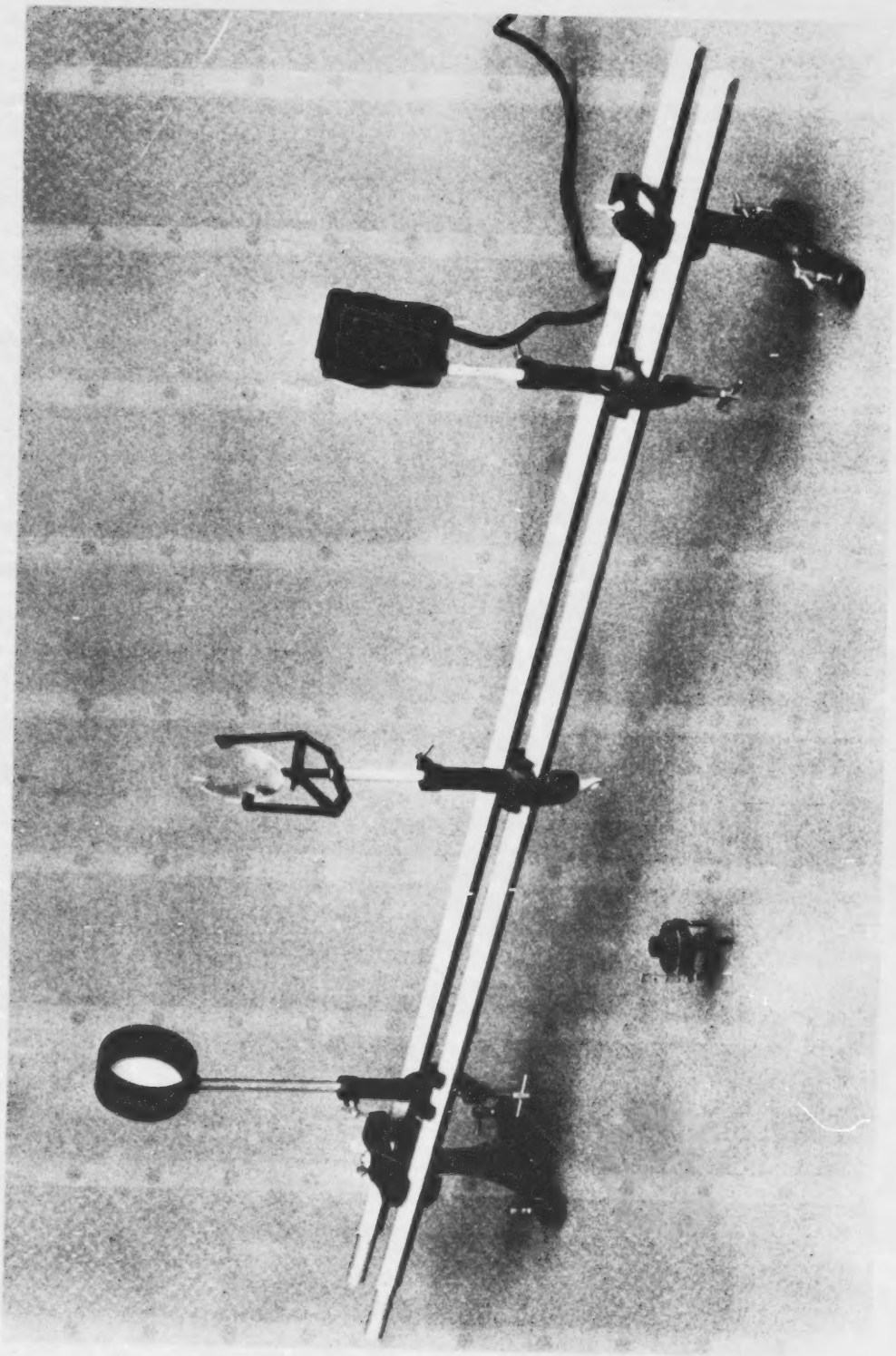

EXPERIMENT XV

Image Formation by a Thin Lens

Purpose:

To study image formation, radii of curvature, refractive index, and focal length of thin lenses.

Apparatus:

Optical bench with three movable mounts; double convex lens of about 20 cm focal length; object light source; image screen; strips of red and blue glass; and metal disks (one about the same size as the lens with an aperture in the center of about 1 cm and one which will cover only the central portion of the lens); spherometer.

Information:

The most frequently observed phenomena encountered in the field of optics are images formed by a thin lens or groups of lenses. A few of the common instruments which utilize these phenomena are telescopes, spectacles, microscopes, cameras projectors, and rangefinders. There are basically two types of lenses, according to their shapes: converging lenses and diverging lenses. Those lenses which are thicker in the center than they are on the edges tend to bend or refract light away from the optical axis and are called diverging or negative lenses.

There are certain basic defects in image formation with lenses. The defect of *spherical aberration,* or indistinct focus of light rays which strike at a distance away from the optical axis, is similar to this defect as found in sperical surface reflectors or mirrors. One of the important defects of lenses is called *chromatic aberration.* It is caused by the fact that light of all colors or frequencies is not bent or refracted the same amount by the lens material. The image will not be absolutely sharp because the lower frequencies (red light) are not bent or refracted as much as the higher frequencies (blue light). A third defect, *astigmatism,* is noted if the curvature of a lens is not the same for all planes through the optical axis. A thin lens will have a small thickness compared to its focal length, and in these situations, the basic lens formula will apply.

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

where:

d_o = distance from the object to the optical center of the lens.
d_i = distance from the image to the optical center of the lens.
f = focal length of the lens.

The above formula applies only to a symmetrical, thin lens, but lens manufacturers make all shapes of lenses. The relationships shown in the lensmaker's formula below is true for all lenses.

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

where:

f = focal length

μ = refractive index of the lens material

R_1 = radius of curvature of first face

R_2 = radius of curvature of second face

R_1 and R_2 are positive if they result in convergence and negative if they result in divergence.

If the refractive index is to be found of a lens material for a lens already manufactured, the lensmakers formula may be solved for

$$\mu = 1 + \frac{R_1 R_2}{f(R_1 + R_2)}$$

Procedure:

Part I. Lens Constant Determination

a. Set up the optical bench with three movable carriers. Place the object light source or object box on the left carrier, the lens and lens holder on the middle carrier, and the image screen in the third position. With object box at the end and lens and lens holder at the center of the optical bench, move the screen until a clear image is viewed on the screen. Record the object-to-lens distance (d_o) and the image-to-lens distance (d_i).

b. Repeat the above procedure, except move the object box closer to the lens while adjusting the image screen for a clear image. Continue this operation until the image distance is greater than the object distance. Measure and record the object distance and the image distance.

c. Take spherometer readings of both faces of the double convex lens. Since both lens faces are spherical, the method used in Experiment XIII may be used to determine the radius of curvature of each face. The radius of curvature formula is:

$$R = \frac{d}{2} + \frac{L^2}{6d}$$

where:

R = radius of curvature

d = the micrometer screw reading above or below the plane of the legs

L = the average distance between the legs

Part II. Chromatic Aberration

Light of different wavelengths is bent or refracted by the crown glass lens by different amounts. Since this is the case, two wavelengths that are as far apart as possible should be used for this part of the experiment. A piece of red and a piece of blue glass will be used to filter out all the frequencies of white light from the object box except those of red or blue, which pass through the glass plates. Place the red glass plate in front of the object box and adjust the image screen until a clear image is formed. Measure and record the image distance for this red light. Replace the red plate with a blue glass plate in front of the object box. Readjust the image screen for a clear image with this blue light. Measure and record the image distance for the blue light.

Part III. Spherical Aberration

Spherical aberration is actually due to the spherical curvature of the lens and not due to light frequency. A nearly monochromatic light – white light passing through the red glass plate – will be used in this part of the experiment to allow the observation of spherical aberration without the interference of chromatic aberration.

a. Place the metal disc with the hole in the center in front of the lens between the object and the lens. This will allow only the light rays near the principal axis of the lens to pass through. Adjust the image screen until a clear image is found. Measure and record this image distance.

b. Place the metal disc with the center covered but the outer edge open between the object and the lens; this will allow only those rays at a distance from the principal axis to pass through the lens. Adjust the image screen until a clear image is formed. Measure and record the image distance.

Part IV. Astigmatism

a. Leave the red glass in front of the lens and rotate the lens mount about its vertical axis while observing the image on the screen. Fix the lens mount at an angle of approximately 45 degrees with its vertical axis. Move the image screen until the vertical lines of the image are clear. The horizontal part of the image will be fuzzy. Measure and record this image distance.

b. Move the image screen until the horizontal part of the image is clear and the vertical portion is fuzzy. Measure and record this distance. This difference in image distance is due to the simulation of a deformed lens.

Calculations:

Part I.

a. From the basic thin lens equation and the image and object distances, compute the focal length of the lens.
b. Use the spherometer equation to calculate the radius of curvature for each face of the lens.
c. Utilizing the focal length and radii of curvature from the above calculations, apply the lensmaker's formula and determine the index of refraction of the glass for white light.

Part II.

a. Utilizing the image distance for red light and the image distance for blue light, calculate, using the basic thin lens formula, the focal length for red and blue lights.
b. Use the radii of curvature calculation from Part I and the focal length calculations from Part II, determine the index of refraction (μ) for the red and then the blue light.

Analysis:

1. Carefully illustrate by the use of diagrams the phenomena of spherical aberration, chromatic aberration.
2. What caused the distortion encountered in Procedure Part IV, Astigmatism, and how can this defect be used to advantage?
3. From collateral reading, explain how chromatic aberration and spherical aberration are minimized in ordinary optical instruments.

EXPERIMENT XVI

Polarization of Light

Purpose:

To study the phenomenon of light polarization, the transverse character of light, and to investigate some practical applications of polarized light.

Apparatus:

Optical bench, screen, diaphragm with variable aperture, light source, Polaroid experimental kit (Bausch and Lomb Inc.), optical bench mounts, convex lens with 20 to 30 cm. focal length, photoelastic material, photoelastic samples, photoelastic stress cycler (Scott Engineering Model No. 9047) and polariscope (Scott Engineering Model No. 9015.)

Information:

Light waves are transverse waves which are electromagnetic in character and travel through a vacuum at approximately 186,000 miles/second. The electric and magnetic vibrations which make up light vibrate perpendicular to each other. Both vibrations are perpendicular to the direction of travel of the wave. Ordinary light appears to be made up of millions of these vibrations; and these waves are vibrating in all possible planes, which intersect in an axis, which is defined as the direction of travel of the wave. If the ordinary light beam could be observed end on from a position along the axis of travel, the waves should be equally distributed in all planes about the axis. This is an example of what is said to be unpolarized light.

In light which is polarized, all the electric vibrations of the electromagnetic wave are in the same plane. There are several ways by which light may be polarized. Some of these are: by reflection from air and dust particles in the atmosphere, by double refraction through material crystals like calcite, by reflection from nonconducting surfaces, and by selective absorption with materials such as tourmaline and other optical substances.

The easiest to use of the above methods is a manufactured material known as Polaroid. This material is made up of small needle-shaped crystals of the organic compound, sulfate of iodoquinine. When these crystals are lined up parallel to each other and imbedded in a nitrocellulose mastic, a thin, plastic-like film, they will transmit nearly all the components of light vibrating in one direction but will absorb nearly all other components of light. The effect is similar to the selectric absorption of light in crystals like tourmaline.

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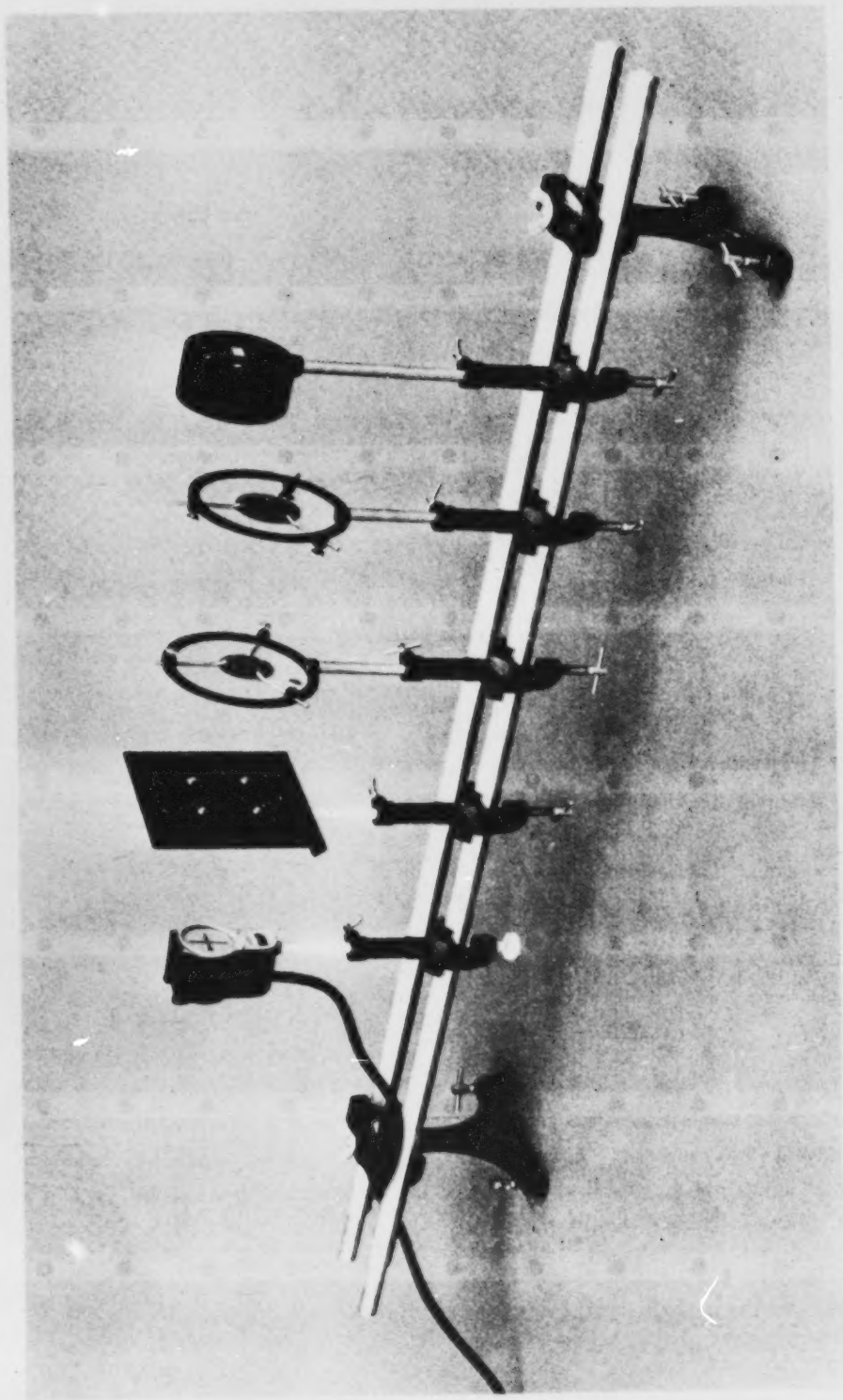

Procedure:

Part I. Observation of the Effect of Double Polarizers

Set up an optical bench with a light source, lens system and adjustable aperture at one end, and a screen at the other end. Adjust the lens for a parallel beam of light and the aperture to a diameter of about 1 inch.

Place one piece of polarizing material from the polarizing kit in the light beam about 5 inches in front of the screen. Place a second piece of polarizing material in the light beam about 3 inches from the screen. Leave the first piece of polarizer in the fixed position, and rotate the second piece of polarizer about the axis of the light beam. Observe and record the effect of this action on the light screen.

Part II. Effect of Crystals such as Calcite, Mica and Cellophane Films

With the second polarizer still 3 inches from the screen, remove the first polarizer and use crystals of calcite and mica and cellophane film in its place. Rotate each of these samples in the beam of light while bending and twisting them. Observe and record the effect on the light on the screen.

Part III. Strains in Transparent Materials

Set up the Scott Cycler Model No. 9047 between the two polarizing plates of the Scott Polariscope model 9015. Use the white-light position of the switch on polariscope model 9015. Insert stress samples in the Stress cycle, observe and record your observations both before and during the time the stress cycler is operating.

Results:

Present your results under the headings listed in the Procedure section of this experiment. Describe exactly what you learned and use sketches to clarify your points.

Analysis and Interpretation:

1. How does this phenomenon of polarization help prove that light is transmitted by transverse wave motion?
2. What are some practical uses of polarization in the glass industry?
3. How do Polaroid glasses reduce glare?

EXPERIMENT XVII

Internal Strain in Glass

Purpose:

To study the effect of heat on the strain patterns in glass.

Apparatus:

Burner, glass laboratory samples and Scott Engineering Polariscope Model 9015.

Information:

Glass at ordinary temperatures is a highly elastic substance, which is obtained as the result of cooling a viscous liquid. The amount of stress in glass is dependent on its total thermal history.

Glass, except at very high temperatures, is a very poor conductor of heat. Therefore, as glass is heated or cooled, temperature gradients are developed. This temperature gradient is the slope of the curve formed when temperature is plotted against the distance from the surface to the center of the object; it describes the lag in temperature between the outside and the inside of the glass.

A change in temperature of a glass object causes a consequent change in length. The external length will be different from the internal length, so stresses will be set up between the internal and external portions of the glass. Wherever there is a stress, there will be strain developed. When viewed under polarized light, these strain lines will appear. If glass is heated to a very high temperature, it becomes viscous enough that these strain strata cannot exist. The problem is how to cool the glass to normal using temperatures without having excessive internal strains develop.

When the glass is cooled rapidly, very large and widely distributed strains will appear. Sometimes these strains are large enough to cause the glass to break without handling or use. There are times, though, when these large and widely distributed strains are not enough to break the glass, and in this case it achieves properties of strength and surface hardness. These will be studied in a later experiment.

Theoretically the proper method used to remove and relieve these strain strata would be to keep the temperature of the glass as nearly the same on the inside as it is on the outside during the cooling process. The term "anneal" is used in the glass industry. The annealing of glass consists of raising the glass object to a very high temperature so that the strains disappear; then slowly lowering the temperature so that the internal temperature remains fairly close to the external temperature.

Procedure:

1. Minimum Strain.

Using a sample of glass tubing fresh from the shipping crate or storage rack, observe and sketch the strain patterns in the glass as seen through a polariscope.

2. Temporary strain

Heat one end of sample glass tubing in steady flame of intense heat. The glass need not be heated to its working point. Remove glass tubing from the flame and insert it between the two disks of the polariscope. Observe and sketch the strain lines along the glass as it is moved between the polariscope disks from the hot end to the cooler end. After heating the tubing again, let it cool normally in the room. Observe it through the disks on the polariscope at about two-minute intervals. Describe what changes occur in the strain pattern in the glass.

3. Permanent Strain

Heat a piece of glass tubing to a moderately high temperature then quickly quench it in a container of water. Place the quenched tube between the disks of the polariscope. Observe and sketch the strain lines in the glass.

Results:

Organize and sketch the strain diagrams and observed material into the body of a report of your data.

Analysis and Interpretations:

1. Would it be theoretically possible to produce a piece of glass completely free of strain?
2. Why is glass at 200° C easier to chip than glass at normal room temperature?
3. A piece of glass has a coefficient of linear expansion of 8.5 X 10^{-6}/°C and a temperature gradient of 100°C. What would this represent in difference in length from outside to inside per centigrade degree?

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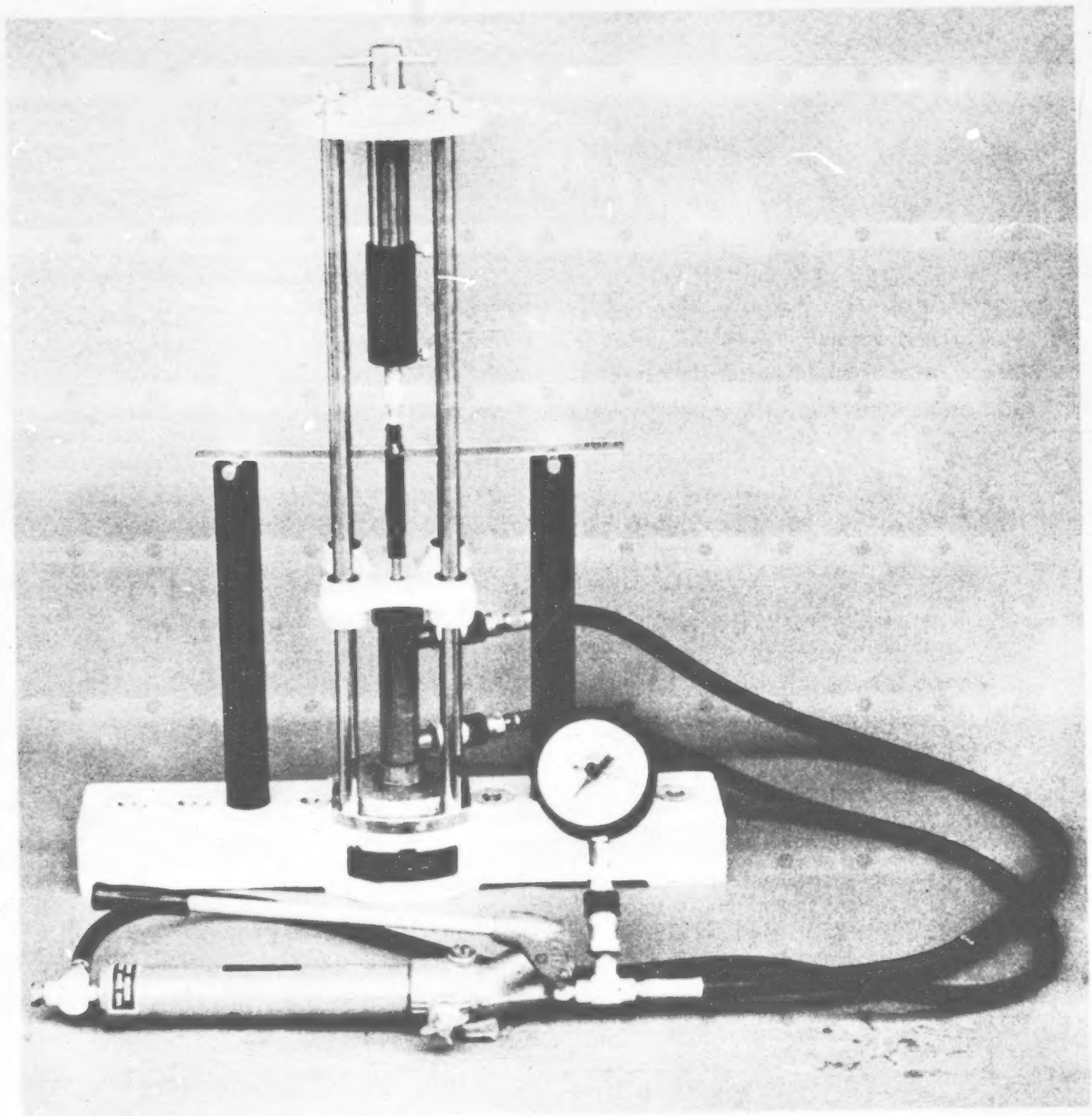

EXPERIMENT XVIII

Glass Tube Bending and Breaking Points

Purpose:

To determine a modulus of elasticity for glass tubing and to determine a shearing force for glass tubing under the following conditions: dust on the glass, grease on the glass, scratches, and wetting.

Apparatus:

Scott Engineering Properties of Materials Test System Model 9014; Scott Polariscope Model 9015; glass tubing specimens dusty from the storage rack and well cleaned; micrometer calipers; and vernier calipers.

Information:

Glass has some unusual properties because, as used in the glass shop, it is a super-cooled liquid rather than a true crystalline solid. It has some of the physical characteristics of solids such as its hardness, solid form, and elasticity. It also has some rather curious properties such as not being plastic at room temperature. If a force is applied to glass, it will bend elastically until it breaks but will not bend elastically and stay partially deformed as will a piece of metal. The modulus of elasticity is normally given by the equation

$$E = \frac{S}{\epsilon}$$

where:

E = modulus of elasticity (psi)

S = bending stress (psi)

ϵ = strain due to bending action (inch/inch)

Glass also has some other strange properties due to its unusual classification. The molecules at the surface of the glass give it much of its strength by cohesive forces called surface tension. If the surface tension is disrupted or the intermolecular forces disturbed, the strength of the glass is drastically reduced. A scratch will disrupt these forces as well as putting a stress into the glass. Dirt, grease, and water will also disrupt the surface tension of the glass. For this reason, wetting a scratch will make a break much easier to accomplish.

Procedure:

1. Set up the properties-of-materials test system in the long configuration for single, central-force beam bending. Place the support posts so that they support the glass rod near its ends. Use support heads 14–09–000. Set up the polariscope so the glass specimen can be observed as it is bent.
2. Set up the Scott strain balance system with the active gage between the glass rod, which will be set in position, and the yoke. Zero the null indicator with the initial balance after the active gage is in position and before a force has been applied.
3. Cut glass tube in lengths of approximately 20 cm and use samples with the following conditions:
   a. Dirty, as from long storage on a rack.
   b. Greasy, as from excessive handling.
   c. Scratched, as for making a break.
   d. Scratched and wetted, as for making a break.
   e. Well cleaned by chromic acid and washed with water and dried.
4. Apply load in 10-pound increments for unscratched specimens and 1-pound increments for scratched specimens and record strain on the strain gage and micrometer until the breaking point is reached.

Results:

1. Observe and sketch the type of fracture that results from each specimen condition.
2. Calculate the modulus of elasticity, using the length of the tube as the distance between support points, and the deformation found by the micrometer to calculate strain.
3. Use the strain recorded by the strain gage to calculate the modulus of elasticity.

Analysis and Interpretation:

1. Describe what effects the various conditions have on the modulus of elasticity, the breaking point, and the resulting type of fracture.
2. Plot the stress vs. strain on a graph. The modulus of elasticity can readily be found from this plot if the stress is plotted vertically and the strain horizontally. The modulus of elasticity (E) will then be the slope of this graph.

EXPERIMENT XIX

Glass Annealing

Purpose:

To study the effect of annealing on internal glass strain.

Apparatus:

Burner, Lehr Muffle Oven, laboratory glass samples, soda lime glass samples, and Scott Engineering Model 9015 Polariscope.

Information:

The internal stresses in glass have been studied in Experiment XVII. The annealing or continuous heat process is the generally recommended method by which stress relief is accomplished. The glass technician must realize and learn to use the benefits that come from heat treating. The temperature gradient developed in glass apparatus will be dependent upon the type of heat applied. If the heat is of the uniform surrounding type, the temperature gradient will be between the outside and inside of the glass structure. If the heat is of the open-flame type, there are at least two possible temperature gradients involved. The first of these gradients is between the side of the material directly exposed to the flame and the side which is opposite the flame. The second gradient is between the heated and the unheated portion of the glass structure.

The temperature of the strain point and the upper annealing temperature are dependent upon the type of glass being used; it is determined by the viscosity, heat conduction, and coefficient of linear expansion of the particular glass. The properties are generally available in the catalog of glass supply companies. A representative table is given below for some common glasses.

Type of Glass	Lead		Soda Lime		Borosilicate	
Name of glass	KG–1	KG–12	R–6 Soft Apparatus Glass	Bulb Glass	N–51A Ampul Glass	K1–33 Hard Apparatus Glass
Working point °F	1778	1796	1803	1832	2157	2264
Softening point °F	1159	1171	1292	1285	1463	1508
Annealing point °F	802	811	972	950	1065	1031
Strain point °F	747	752	919	892	1008	959
Coefficient of expansion ($\times 10^{-7}$/°C) (From 0°–300°C)	94	89	93	92	49	32.5

A very important property of any apparatus glass is heat shock or thermal endurance. This is the ability of a material to withstand sudden changes in temperature without breaking. Thermal endurance is largely a property of the coefficient of expansion. Referring to the table for this experiment, it will be observed that the expansion coefficients vary from 32.5 x 10^{-7}/°C to 94 x 10^{-7}/°C. The glasses with low coefficients of expansion can be cooled faster after working without developing excessive cooling strain. The glasses with high coefficients of linear expansion must be cooled slowly, or they could crack before they can be gotten to the annealing oven. If done properly, most of the internal strains can be removed in the flame where the glass was worked.

The upper annealing temperature is at a point where the material is viscous enough so that the glass is no longer elastic and the stress will not cause a strain. Yet, it must be below the temperature at which the glass object would distort in shape. The upper annealing temperature is very close to the softening temperature of the glass, so that this temperature will seldom be used in the annealing process.

The temperature generally used for annealing is from 50° to 75° above the strain point. This strain point is the point where the material has regained the elasticity normally associated with a solid. This is the point where an annealing time of four hours will not remove the internal strains. A 4-hour period is actually an excessive annealing time, because 90% of the internal stress is removed in two minutes at the upper annealing temperature.

The annealing temperature actually used will depend mainly on the expansion coefficient of the material, the time allowed for annealing, the residual strain desired in the material, and the method of annealing to be used. Once the temperature has dropped below the strain point, the internal strain is fairly well fixed into the glass.

Flame annealing is the method used to anneal the glass while it is still in the working flame. To anneal the glass structure, it is rotated and moved back and forth in the flame to reduce all temperature gradients to a minimum while raising the glass to the annealing temperature. The annealing temperature for flame annealing would approach the upper annealing temperature for the type of glass in order to reduce the annealing time. After the annealing temperature is reached and while rotating and moving the apparatus, it is gradually lifted out of the flame until uniform cooling has occurred and the temperature has dropped below the strain point. This type of annealing must be done with soft glasses that have a high coefficient of expansion and may be done with thin-wall hard glass. This process will remove the major portion of the internal stress from the glass.

The Lehr furnace technique of annealing is the method used for maximum or specific relief of internal stress. It uses a lower annealing temperature for longer periods of time. This process gives much better control and uniformity of the annealed end

product, though the time may be measured in hours. This is not a disadvantage because furnaces have been built which are highly instrumented, and the temperature and time can be automatically controlled. The operator simply places the glass in the oven and the temperature is raised at a rate set by the operator. This leaves the operator free to go back to glass fabrication while the equipment is being annealed. This process will be used for specific residual-strain annealing and for heavy-wall or large glass apparatus.

Procedure:

Part I. Flame Annealing

a. Fabricate a simple laboratory apparatus from soft glass. As soon as the apparatus is completed, remove it from the flame and let it cool in the air. Place the apparatus for viewing with the Scott Engineering Polariscope Model 9015. Observe and record the strain lines in the apparatus.
b. Fabricate a soft-glass simple laboratory apparatus as in (a), but make sure the complete apparatus is rotated and uniformly heated in the working flame as the unit is completed. Gradually lift the apparatus out of the flame and allow it to cool uniformly under the influence of the flame. Place the apparatus between the discs of the Scott Engineering Polariscope Model 9015. Observe and record the strain patterns in the apparatus.
c. Repeats steps (a) and (b) above for a thin-wall hard-glass apparatus.
d. Repeats steps (a) and (b) for a heavy-wall hard-glass apparatus.

Part II. Lehr Furnace Annealing

a. Place the apparatus fabricated in part Ia in the oven. Set the automatic instrumentation to take the temperature up rapidly to the maximum and then rapidly cool the apparatus. After cooling, remove apparatus from oven and place it between the discs of the polariscope. Observe and record the internal strain patterns in the apparatus.
b. Place the apparatus used in part IIa in the oven. Set the automatic instrumentation to raise the temperature to the maximum slowly and then cool it slowly.
c. Repeat Steps IIa and IIb with the apparatus fabricated in part 1c.
d. Repeat steps IIa and IIb with the apparatus fabricated in step 1d.

Result:

Use the observations and sketches recorded in the measurements section of this experiment and discuss what you have learned about glass annealing.

Analysis and Interpretation:

1. From collateral reading, discuss the methods and application of glass annealing in the glass industry.
2. Why is proper annealing of critical importance in optical glass?
3. Explain why there is a difference between the annealing procedure of soft and hard glass.

EXPERIMENT XX

Glass Strength Testing

Purpose:

To study methods of strength-testing glass apparatus.

Apparatus:

Scott Engineering Properties of Materials System Model 9014, Scott Engineering Polariscope Model 9015, and soft and hard glass samples.

Information:

Except for glass which is to be used for optical applications, the most important of its properties is its mechanical strength. In all types of glasses the measurement of its mechanical strength is a much more difficult task than the measurement of its optical properties. The modulus of rupture is the tensile strength when measured by bending rather than direct axial stress. One of the most important mechanical properties of glass is that the compressive and shear strengths of glass are almost infinite.

In practical applications where shear or compression are attempted, some bending will occur. Thus, a tensile stress and consequent failure are induced.

Several of the factors concerning the effect of surface scratching, or wetted surface of glass, have been studied in the experiment dealing with glass bending and breaking. This experiment dealt with finding the modulus of elasticity by the bending method. The difficulty in applying this to glass apparatus is that it measures the weakness of the surface; the condition of the surface depends upon whether it has been scratched, touched, or simply left in the air to age.

The bending moment under a single concentrated load varies from zero at the supports to maximum at the center where the load is applied. This gives the maximum bending moment only at this central point; and the modulus of rupture from this experiment is not as accurate as most scientists think it could be.

Very little experimentation has been done with so-called no-shear load testing, or the use of two equal loads equidistant from the center. This type of loading produces a bending moment throughout the distance between the two loads which is constant and equal.

This loading should give more uniform results than the central, concentrated load and will be the method used in this experiment.

The glass sample is length L_1, and the distance between the loads is L_2. If L_2 is equal to one half of L_1 and $F = P$ (ram area), then the bending moment may be found by the formula developed below.

$$M = \frac{PA_r}{2} \quad \frac{(L_1 - L_2)}{2} = PA_r \frac{(L_1 - L_2)}{4}$$

where:

M = maximum bending moment in in.-lbs.

P = pressure reading from hydraulic gage

A_r = ram area of hydraulic piston

= .223 in^2 when shaft is retracting

= .373 in^2 when shaft is extending

L_1 = length of rod between the supports in inches

L_2 = distance between equal loads in inches

If: $L_2 = \frac{L_1}{2}$

Then: $M = \frac{P A_r L_1}{8}$

The maximum tensile stress developed will be, according to the study of strength of materials,

$$\text{Rupture stress} = \frac{M}{Z}$$

Where the beam is symmetrical:

solid circular $Z = \frac{d^3}{32}$

tubular circular rod $Z = \frac{d_1^4 - d_2^4}{32\, d_1}$

rectangular rod $Z = \frac{b\, h^2}{6}$

Where:

Z = section modulus in inches

d = diameter of solid rod in inches

d_1 = outside diameter of tubular rod in inches

d_2 = inside diameter of tubular rod in inches

b = width of rectangular rod in inches

h = height of rectangular rod in inches

Procedure:

Part I. Solid glass rod

a. Place ¼-inch-diameter solid soft-glass rod in Scott Properties of Materials Test Set as shown in photograph. Be sure that the large hose from the hydraulic jack is connected to the top of the jack.

b. Read and record rod diameter and length between supports.

c. Pump up the pressure using the hydraulic jack until rupture of the glass occurs. Read and record the pressure on the gage at time of rupture.

d. Repeat steps (a), (b), and (c) for ¼-inch-diameter solid hard-glass rod.

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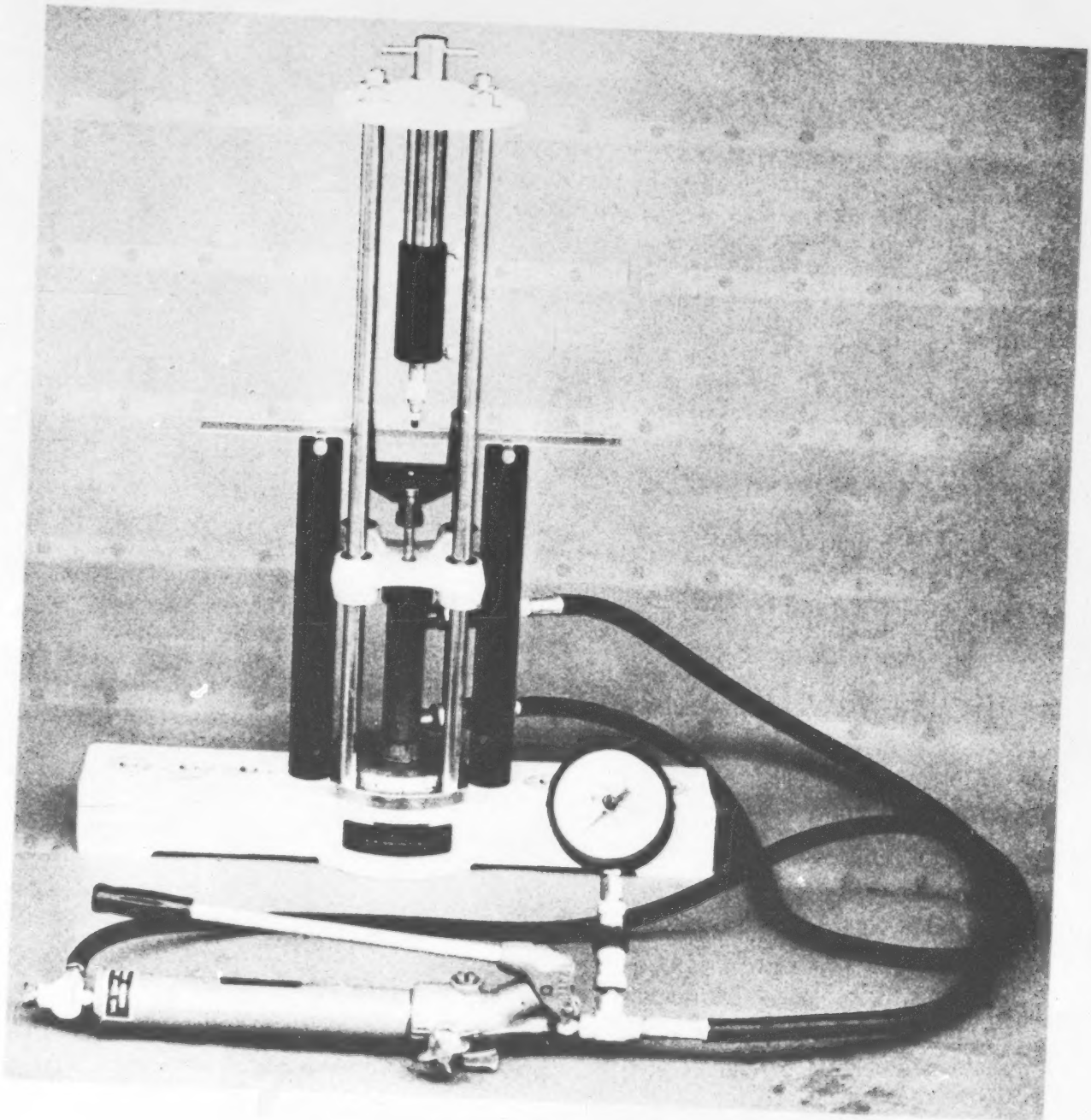

Part II. Tubular glass rod

a. Place ¼-inch-outside-diameter tubular soft-glass rod on Scott Properties Materials Test Set Model 9014 as shown in photograph. Be sure that the large hose from the hydraulic jack is connected to the top of the jack.
b. Measure and record the outside and the inside diameter of the rod and the length of the rod between the supports.
c. Pump up the pressure on the gage until the glass rod ruptures. Read and record the pressure of the gage at the time of rupture.
d. Repeat steps (a), (b), and (c) for ¼-inch-diameter hard-glass tubular rod.

Results:

1. Using measurements from part I, calculate the bending moment (M), section modulus (Z) and the rupture stress on the solid glass rods.
2. Using measurements from part II, calculate the bending moment (M), section modulus (Z) and the rupture stress on the tubular glass rods.
3. Compare the results of the rupture stress calculations for this experiment with those of the other members of the class.

Analysis and Interpretation:

1. If there are discrepancies between your findings and those of your classmates, what are some of the possible causes for these discrepancies?
2. How do the results of the experiment compare with the results of Experiment XVIII on glass tube bending and breaking?